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Cover illustration: Thin sections of several different habits of barite. Photographs: Jane Clarke.

Botryoidal barite Mag 538; ppl.	Acicular barite Mag 549; xpl.	Poikilotopic barite Mag 530; xpl.
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Entering Geology's Third Century - What have we learnt?

Hugh Torrens - (formerly) University of Keele

Well it's nice to be here, thank you for your kind welcome. I talk as we enter Geology's third century, our new science having - by common consent - only having been invented around 1800 as a result of international activities in Germany, France and Britain. I want here to ponder what have we learned and where have we come from in this historically short period. I start with some nostalgia, back to when I was about fifteen. I recall a most remarkable man who became my geological mentor, a former schoolmaster and clergyman called the Reverend Joseph Fowler (1872-1958), an enthusiastic member of the Geologists' Association. He encouraged me at my Dorset school. Although it was an expensive school and I was a privileged child, I was not allowed to study Geology there as it was "not on the curriculum". Fowler's encouragement made it possible for me to take on an extra A level in Geology (1959) without any tuition. I have ever since felt that 'motivation' is a MUCH more important word than 'curriculum' (which I have learnt to loathe). I remember that the first coloured Geological Map I ever saw was during my theses exams, but I'd done so much geology that I was able to work out what must be happening. I passed, much to my delight, and his as well. Fowler was an enthusiastic member of many voluntary societies and I pay tribute to this very English way of getting things done. His grandfather William (1761-1832) had been an architect and a very fine artist and draughtsman. He drew some Roman pavements found in Lincolnshire in about 1810 for Sir Joseph Banks, the President of the Royal Society, who said of them:

> "Others have shown us what they have thought these Roman pavement remains ought to have been but Fowler has shown us what they are" (quoted in the *DNB* entry for William Fowler - 1761-1832).

In other words, Fowler had faithfully represented only what was in front of him. This was an important point in those days, when people were trying to restore and improve things too much.

In 1807 this same Joseph Banks - the first of many such connections in this lecture - had employed another remarkable man called John Farey (1766-1826 - the colleague and pupil of William Smith, supposed father of English geology) to make a mineral survey of his Derbyshire estates at Ashover. This place, more connections, was where I, as an undergraduate, did my first geological mapping. It has a beautiful view from its Ashover Grit rim into a beautifully exposed anticline with its central eroded core of Toadstone or Tuff. Many years later I found Farey's remarkable original MSS map showing the geology there, in a library in California. It was drawn for Sir Joseph Banks in 1812 but had never been published. It was based on a topographic basemap that Farey, a fine land-surveyor, had first had to compile himself, because there were then no Ordnance Survey maps on which to base the geology. When he finished it in 1812 the Geological Society of London refused to publish it because it had not been constructed according to the criteria they then held were 'in vogue'. This amazing map was only published in 1994 (Banks *et al*. 1994 p66). Things being 'in vogue' is a point I will return to. I was taught about the crucial business of making geological maps at Ashover. The map we used then was that published by Godfrey Himus (1894-1964) and George Sweeting (1889-1977) in *The Elements of Field Geology* (Himus & Sweeting 1955, plate 2). It marks the site of Banks' fine house there, Overton Hall, and shows the Toadstones and the structure here - a beautiful eroded anticline. In this modern map, first drawn in 1948-49, only a few rocks are separated: Toadstones [tuffs], Carboniferous Limestones, Butts Shales, Kinderscout Grit, Grit Shales, Chatsworth Grit, Alluvium etc, all very simple. Another connection is that Himus went to the same Petersfield school as the man who had inspired me, Joseph Fowler, another of these wonderful connections which history reveals between generations. I have already mentioned that the Geological Society. would not publish Farey's map because it was "too detailed" and was not done using the "right criteria" . This leads to my first question. How do we know whether all that is 'in vogue' is actually good science or not?

Farey's more detailed map is a most remarkable document. As David Oldroyd, an Australian historian, has noted,

> "if one did not know the date, one might easily suppose by its appearance that the map was a late nineteenth century production. This discovery suggests that there was probably a much stronger tradition of geological cartography in the early nineteenth century than has previously been supposed" (Oldroyd 1996 p114).

In other words, Farey's detail predates our expectations by about a hundred years. This then suggests that what we know about the past may prove rather incomplete and episodic (just like the geological record!), and may allow us to draw some lessons from history. The first is one of the themes I will return to in this lecture. This is that Farey was a Loser - nobody has heard of him - who should be better known than he is. On top of his geology, he was also a remarkable mathematician (Farey numbers are named after him), and was also one of the world's experts in musical theory. If you saw the recent TV programmes on Equal Temperament in Music, work on this vexed topic was another of his achievements. He was busy uncovering the mathematics involved behind the search for equal temperament in music.

My second lesson is that the "ruling classes" do not always get things right, then or now! This wonderful map was judged inadequate because it was done on the "wrong" principles and was "too detailed". But every time I look at it, I'm just bowled over by that detail, which is so much better than I could aspire to as an undergraduate even 150 years later. I wake up in a cold sweat wondering what the current "ruling classes" would have made of it now, in their monstrous 'Research Assessment Exercises', if poor Farey had the misfortune to work in one of our Universities! My third lesson is that the past has many more such surprises waiting for us, about who did what and when. There must be other such materials waiting to be discovered (just as Farey's map was). Historical research is just as alive as any science is (although much less encouraged and supported) and we should be looking for and encouraging this sort of quest more. My final point is that Farey's case as a Loser is not unique; such Winners and Losers are really rather commonplace throughout history.

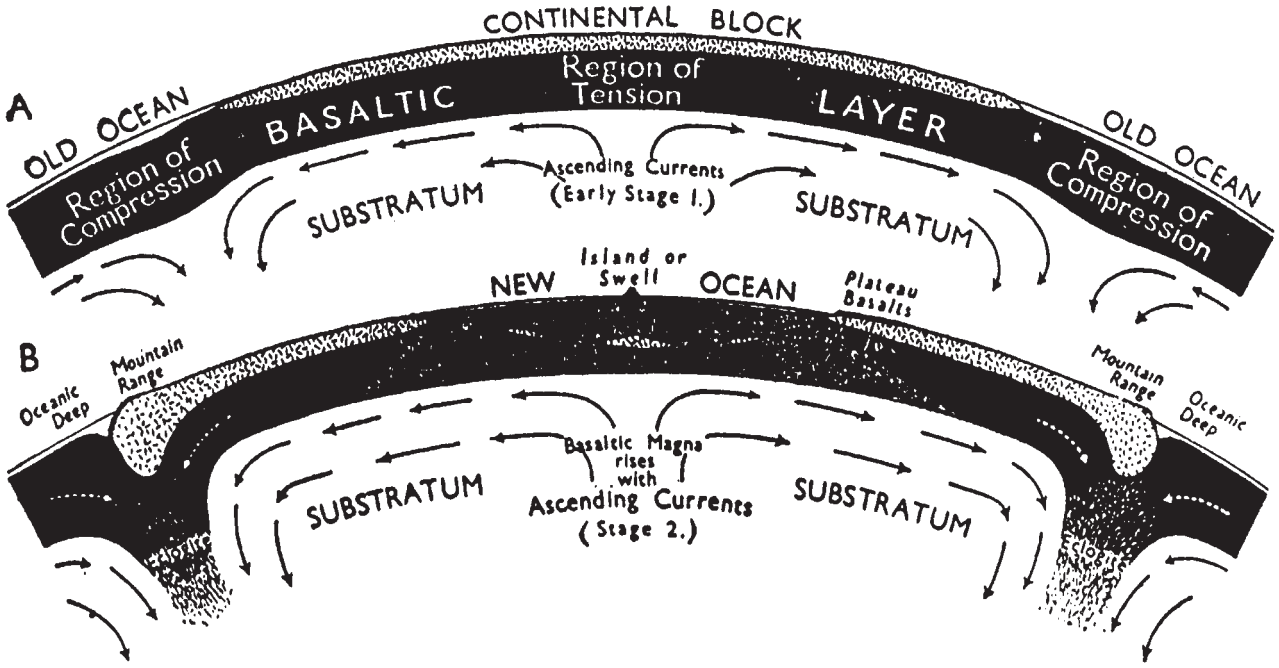

FIG. 262

Diagrams to illustrate a purely hypothetical mechanism for "engineering" continental drift. In A sub-crustal currents are in the early part of the convection cycle (Stage 1 of Fig. 215). In B the currents have become sufficiently vigorous (Stage 2 of Fig. 215) to drag the two halves of the original continent apart, with consequent mountain building in front where the currents are descending, and ocean floor development on the site of the gap, where the currents are ascending

Figure 1. Arthur Holmes' diagram from his *Principles of Physical Geology* 1944. Permission to reproduce this figure has been kindly granted by Mrs Jean Duff, the copyright holder.

You will all have, at least, heard of my next example of a Loser, Alfred Wegener (1880-1930) who died in Greenland on a polar expedition in 1930 aged only 50. He was reviled in his day both because he was German and a meteorologist but who had come up with an important geological idea just before the First World War. He thought the present continents had drifted! Everybody that mattered (those 'research assessors') knew this was impossible, simply because there was no known mechanism/process by which such drift could have occurred. Wegener didn't worry about processes - he worried about facts and to him these demanded that there had to be an, as yet unknown, explanation. But the assessors said he was wrong and he was marginalised. Of course not long afterwards seafloor spreading was discovered, and people found he had got remarkably close to the truth. He has now became a latter day Winner. If you want to know more about how passionate, and how different, transatlantic reactions to these topics were, read Naomi Oreskes' fine new book (Oreskes 1999).

On any palaeo-magnetic map of Iceland you can see plotted, astride the mid-Atlantic ridge, those beautiful coloured stripes - the most recent in the middle, but on either side evidence of that wonderful polarity that proves how events started from the spreading ridge with the bilateral polarity indicating the speed at which things had happened. This concept came in the 1960's as a revolution! I was a student at that time and recall being taught by two groups of people, traditionalists who said it had all been proved wrong long ago and modernists who said there was something interesting going on! It was wonderful to be taught during such schizophrenic times by some people who didn't know all the answers and who so encouraged me to think for myself. This seems exactly to have been what did not then happen enough in the USA, where there was then a more 'official line' which encouraged rejection (and this in the land of the free!). This is another aspect of modern university education which worries me. We are being encouraged to suppose that there are 'simple answers' which we must give to students, and then fail them if they do not regurgitate them. As historian and, I hope, geologist, I've learned that there can be many different answers and we have to continue to encourage people, in particular the next generations of students, to think for themselves as I was (and not simply to 'know the answers').

It was the Americans Harry Hess and Bob Dietz who came up independently with the idea of plate tectonics in 1960-1961 but this was nearly 20 years after another remarkable Englishman called Arthur Holmes (1890-1965) had published his *Principles of Physical Geology*. You might like to look at his diagram (Holmes 1944 p506) to see how close he got to today's known principles of mid-Atlantic ridges with ascending and descending magma currents, sub-strata, oceanic deeps and mountain ranges (Figure 1).

This was in 1944, well before any theory involving plate tectonics was promoted. But Holmes got so near the truth that he should be regarded as another of the fathers of plate tectonics. He knew drift must have happened and proposed a mechanism. Arthur Holmes' biography has just been published (Lewis 2000). Please read it. He is one of our most unsung geologists but certainly one of the greatest geologists of the nineteenth century, who held chairs at Durham and later Edinburgh. Proof of the mechanism by which drift occurred was presented on 7 September 1963 when Fred Vine (born 1939 - but whose death was so prematurely announced in Chambers' *Concise Dictionary of Scientists*, 1989, p.388 - beware of what you find in print!) and Drummond Matthews (1931-1997) published their paper on Magnetic Anomalies over Ocean Ridges in *Nature* and persuaded the world this was how plate tectonics happened and the mechanism by which it worked (Vine & Matthews 1963). Vine and Matthews immediately became two Winners and Holmes got forgotten. You may not have heard of another Loser, Lawrence Morley of Canada. He had written a paper with the same idea as Vine and Matthews in December 1962 but which was rejected both by *Nature* (by June 1963) and the *Journal of Geophysical Research* (by September 1963) as being "too speculative". He was an unknown Canadian and did not have the strength of a mainstream Cambridge Department to support him, so he too became a Loser. He became a double Loser when in July 1978 his papers were destroyed in a fire at his Canadian home; Canadian homes are often built of wood and they don't survive fire. So you can see that it is often very difficult for historians to discover what actually happened and when. The complexities of who become Winners and who Losers are never-ending. Morley's case is revealed as well as it can be in Bill Glen's fine book (Glen 1982).

Half the fun of being one of the very few people in Britain who takes an interest in the history of this subject is to try and highlight milestones in geology as they have developed over the last 200 years or so. I would have expected this to be a more common form of 'millennium worship' in 2000 than it has been. The only person I've seen who has published something on this is Simon Conway Morris in *Earth Heritage Magazine* (Conway Morris 2000) although there is an earlier paper, Twelve Key 20th-Century Discoveries in the Geosciences, (Lowman 1986). Conway Morris's top ten were:

1) the geological map,

2) the thin section,

3) plate tectonics,

4) deep drilling,

5) seismics,

6) isotopes,

7) impacts - things that have hit the earth,

8) the Medusa Effect [the preservation of soft-bodied fossils],

9) the Cambrian 'explosion',

10) 'the most influential geologist' Charles Lyell.

Numbers 8 and 9 are, as with any good scientist, largely self-indulgent. These are the fields in which Simon has made his own major, and undoubted, contributions, and he is here trying to defend them. It's a very personal list but I don't think that matters in the slightest. The things I'm most struck by are first how many of the breakthroughs in a supposedly scientific list are entirely dependent on technology. If I were to declare my one over riding enthusiasm in research this would be for more history of technology. I hope very much that you later went to Colin Small's lecture at your Bridge to the Future Symposium? It sounded absolutely fascinating to learn exactly what sand grains can do to jet turbines. This is how the bigger technical problems are revealed and the major advances are made. You saw a Powerpoint presentation here just before me and you must all know what the mobile phone can do (I hope not during this lecture!). We are now busy living through a major technical (electronic) revolution and if we don't keep up with it we will be in deep trouble. I feel that on Simon's list, nos 2) thin section, 3) plate tectonics, 4) deep drilling, 5) seismic investigations, gravity maps and magnetics and 6) isotopes were all the result of technological advances and thus not primarily scientific advances in the first place. Of course, much of the history of geology has been subject to such technological control because of the invention and advance of the motor car and the never ending need to find fuel for it. The first was Carl Benz' 1886 model, preserved in the Deutsches Museum in Munich. It may look rather out of date but, for somebody like me who thinks he understands these things a little, the only major thing we've lost is the large fly-wheel: almost everything else is the same - we've put a closed body on it, and made it much more comfortable, we've put two wheels on the front instead of one, and made it safer, but almost everything else in 1886 was cutting-edge technology. It is a tribute to Benz that he has had such an incredible influence on us all.

I much regret the long, and appalling, lack of interest in the history of technology in Britain. In a recent paper (Torrens 2001) to be published soon, I point out that there are circa 80 chairs in the history of technology in America, where the word "technophobe" is almost unknown and where careful genetic modification of food is accepted without people getting hysterical about it as here. Might we not trust our technologists a little more instead of the mistrust of them led by the popular press? There are about 24 chairs in the history of technology in Germany, who use their technical skills to sell us their cars. How many are there in dear old [sic!] Britain, which is where so much technology started with our Industrial Revolution? We have one chair in the history of technology. My attempts to encourage people to study and understand the history of our ability to do things - i.e. technology - were met with scorn at my former university. It was a subject not thought worth bothering with.

A third point about Simon Conway Morris' list is that it is strongly academic. There is very little in it which concerns the 'real world'; for instance the geology that helps find the petrol that goes into the gas-guzzlers created by Benz. His didn't guzzle much gas, it didn't travel long distances, but my goodness, it started a trend! We are now addicted to petroleum and that addiction, and our ability to control it, is going to affect my, and your, children in a remarkable way. The sooner we warn them to think about alternatives and get them to worry about the future instead of moaning about the present price of petrol (never its future availability, I note) the better.

Remarkably, the list of millennial advances I produced and Simon's list have much in common. Six of my dozen are essentially the same. I called 1) the ability to identify strata, as on Farey's 1812 map, but this is nearly the same as the Geological Map of Simon's list. I put 2) microscopy, where he put thin sec-

tions. 3) the antiquity of the earth, where he put isotopes to investigate the age of the earth, 4) continental drift = his plate tectonics, 5) geophysics = his seismics and 6) Impactology. My others were 7) the recognition of Igneous and 8) Metamorphic rocks, 9) geochemical prospecting (all James Hutton), 10) Glaciation (Louis Agassiz), 11) the recognition of monstrously large animals in the past (Cuvier, Mantell, Owen, Anning) and 12) precision in historical geology (S S Buckman). So we are often in general agreement. We both think geology is rather a young science. But there are also a number of differences between our lists. Why is this? I think this is partly: 1) because I took a longer look - back to the 18th Century and 2) because there have been, and continue to be, deep contentions about what geology actually is, should be and was in the past. One camp has been, and still is, most concerned with the history of the earth, what happened at specific points in its evolution and this is what we might today call historical geology or stratigraphy or something like that. This focuses on the one unique feature which separates our science from all others, the question of time. The other camp is more concerned with causes and processes in geology. I would also add that these often tell us not how things did happen, but more how they might have happened - there is no certainty they did happen, process driven geology is mainly telling us what is possible, only detailed historical analyses may tell us what actually did happen.

But, as a rule, those people who have studied processes and mechanisms have been the more honoured as having made with hindsight bigger contributions to geology. James Hutton, who climbed the Wrekin, so close to us here today, in 1774 looking for primitive rocks (Jones *et al*, 1994 p651), did not analyse history; he was then more interested in the processes by which the earth was formed and made a wonderful series of contributions, albeit one-sided. Simon Conway Morris similarly claimed Charles Lyell (1797-1875) as his 'most influential' geologist. Of course he was, but this was largely because he trained as a lawyer and knew how to write particularly persuasive English. But his book *The Principles of Geology* was again about the processes the earth had undergone, i.e. the present may possibly hold the key to the past, etc. Louis Agassiz (1807-1873), the Swiss who discovered and pioneered a new theory about glaciation has also, rightly, been honoured. Plate tectonics, that modern revolution, was another process which happened, and what we may call today "impactology" has become another recent geological process. It is clear that process geology has been more honoured while the investigation of what actually happened in the geological past has been less honoured. And, of course, computers and models can now show processes happening on screen, which is wonderful but does not prove that such things did happen in the real past! People can be seduced by this wonderful new technology into thinking anything is true. I have already warned you to beware of the (expensive but refereed) printed word. We need to be even more careful of our (cheap and unpoliced) computer screens (see Allen *et al* 1999). Try going onto the web to look at some dirty pictures! You'll find the girls are much "better" looking than the ones you actually manage to deal with and then they get up to far more exciting things than you ever do - this is not any real world, it is part of the seduction!

I would like people today to honour more the contributions from both camps; process-driven discoveries and historical investigations equally. I would urge on you a book with a chapter by H H Read (1889-1970) called *The Historian as Geologist* (Read 1952). This urges the importance of the historical aspects of geology. John Dewey in his acceptance speech for the Wollaston Medal, the premier medal of the Geological Society of London, in 1999 made many of the same points. His is one of the most persuasive pleadings I've ever read (although from what I have heard since it may have been counterproductive). He points out how there has been:

> "a creeping and insidious 'takeover' of the basic core of geology by geophysics and geochemistry. [These] are not independent subjects but tools like the field geologist's hand-lens, hammer and boots.... I believe this is happening because physicists and chemists have begun to take over the fundamental core of our science and many are denigrating the fundamental core of field-based geology as old-fashioned pseudo-science. The truth is the reverse." (Dewey 1999).

Core field-based geology, like Farey's 1812 map, are for me, and clearly for Dewey, the most important, challenging and demanding parts of our science. These are what makes what we do, as geo-scientists, unique. Field-based geology is much like a great deal of modern biology, a profoundly difficult and complicated observational science based often on historical analysis.

Steve Gould commented on this problem in his book *Wonderful Life* on the Burgess Shale in 1989 (Gould 1989). You may not all agree with his conclusions; Simon Conway Morris certainly did not and wrote a riposte pointing out that Gould may not on occasions have been able to tell his animals heads/arses from their heels/elbows (Conway Morris 1999). That doesn't really matter - the point that Steve was making was much more important and subtle. He pointed out that historical explanations in science are distinct from experimental explanations in so many ways. The issue of verification by repetition does not arise with historical analysis. You can go to Woolsthorpe in Lincolnshire and see Isaac Newton's original house. You can see an apple tree (claimed to stem from the original), but you cannot see the apple that either hit Newton or landed beside him (according to the mythology) to inspire his gravitational thoughts, because that was a unique event in history. As Steve noted:

> "The law of gravity tells us [only] how an apple falls, but not why that apple fell at that moment, and [especially not] why Newton happened to be sitting there, ripe for inspiration. The issue of prediction, a central ingredient in the stereotype, does not enter into a historical narrative" (Gould 1989 p278).

Such historical narrative is a much more subtle matter than mere prediction by models and the whole historical complexity of the geological record (and its connections to the historical record!) are things that I would urge you to ponder more. There are people around - I was sad to see some may have been addressing you this same weekend! - who are trying to make the past world appear a merely simple one. Don't let them persuade you! Get your barracking boots on and your megaphones out and tell them how this lecturer told you this is too great an oversimplification. See how they reply! There are great differences between experiment and history happening - as Steve says,

> "These differences place historical, or narrative, explanations in an unfavourable light when judged by restrictive stereotypes of the "scientific methods" . The sciences of historical complexity have been demoted in status and generally occupy a position of low esteem among professionals. The distinctions have entered our language and our metaphors - the "hard" versus the "soft" sciences, the "rigorously experimental" versus the "merely descriptive".

The result is that real science is seen only to be done by men [sic] in lab coats using black boxes and so much geology gets excluded! This is the problem, much of geology is not about 'hard science'. Our science is characterized all through by its historical complexity. As Steve says:

> "we shall never be able to appreciate the full range and meaning of science until we shatter the stereotype of ordering by status and understand the different forms of historical explanation [as in geology] as activities equal in merit to anything done by physics or chemistry" (Gould 1989 pp278-281).

I say "Amen" to that. It is time we faced that reality. If you want to see an example of the problem, re-read Chris Hawkesworth's Symposium 2000 Abstract, which talks "of a fundamental shift in focus from describing what we see in rocks to seeking to understand the processes that formed them". This sounds like an OU mission statement! The historical record in geology and its explanations need to be kept together, not " fundamentally shifted". Or read the review which appeared in the *New Scientist* of the Geological Society's 1992 book *The Geology of England and Wales*. This claimed:

> "Books like this reflect an unashamedly traditional view of geology as they catalogue rocks by age. Geology has [since] moved out of the archive and into the laboratory. Processes, not a mere listing of the products, hold the key to understanding. The pigeon holes that the Geological perpetuates risk stifling modern undergraduates in a morass of trivia..... [only] if we look beyond the mere listing of facts geologists can begin to quantify earth processes, then make and test predictions" (Butler 1992).

In other words, this man wants to be seen doing as "hard science" as possible. But he may be going to make predictions which prove not to have had much relation to what actually happened.

That same book of 1992 (Duff *et al*. 1992), whatever its faults as a stratigraphy book, was very misleading on the subject of history. Its frontispiece showed a picture of "William Smith's house near Bath". When I last went and asked a very nice lady who lived there if it was really the house in which Smith had lived, she said "it must be - all the tourists come here!". Sure enough there is an old plaque announcing this is Smith's house attached to it to 'prove it'! The trouble is, it is demonstrably not Smith's house. That plaque had already been moved onto this house from another nearby, which had been equally wrongly sited. That original plaque was erected in 1890, moved to its present location in 1927. Here it has remained on the wrong house, despite twenty-five years of people telling "the authorities" what is wrong. Nobody cares, nobody worries about the truth. Such sanity only gives us sanitized history! The real house is down the road - you can see the wrong house from it and it is surely time we tackled this problem and got the plaque moved. A parish boundary runs between the two houses, so there is no doubt that the plaque is not only on the wrong house but in the wrong parish! I wish we could get something done about it, but the inertia of the management, to whom I will return in my castigation of managers, must be seen to be believed. The 'truth' was first revealed by the late Joan Eyles (to whose Smith researches I pay tribute) in a paper published in 1974 (Eyles 1974).

Returning to Winners and Losers, in 1992 I went back to the National Academy of Natural Sciences in Philadelphia with a National Science Foundation grant to try and sort out their old Geological collections. They were offering dino-science to the public, as usual. That's sadly all that too many people think is interesting in geology. The first thing I was struck by was that exactly a hundred years before, in 1892, one of their authors had read a paper entitled "Remarks on the quantity, rate of consumption and probable duration of North American coal and the consequence to air-breathing animals [in other words us] of its entire consumption (Wister 1893)." This remarkable man was 'being green' about a hundred years before anybody thought of the possible problems ahead. History has all sorts of things to teach us. One of the reasons I was in Philadelphia was to hunt for lost specimens of the fossil *Trigonia* which is common in the Portland Stone of Dorset and Wiltshire. But these were unique specimens recorded in 1848 and 1849 as showing the presence of preserved soft tissues in these quite ancient fossils. Things as subtle as gills were claimed to have been preserved, as well as adductor muscles and siphonal openings. These were the first fossils apparently in which anybody claimed that such 'soft-body preservation' was both conceivable and proven. Sadly the man who made this discovery, Edward Charlesworth (1813-1893), was *persona non grata* at the Geological Society of London. He intended to publish his work in a journal of which the Geological Society of London did not approve and which (probably as a result!) folded up for lack of subscriptions. So we have more politics in our wonderful science of geology and another Loser. His intended paper was illustrated by a plate showing an almost entire Trigoniid animal with gills and muscles all beautifully preserved. Another internal cast was polished to reveal the gill fibres.

These specimens are now known to be about 150 million years old - could you, in 1849, have imagined such gill fibres being preservable? Of course you can now, because you've since seen Cretaceous fish from Brazil, and you now know what is possible in the fossil record. This plate recorded for the first time that such preservation was conceivable.

All three original specimens had been found by an English collector, been sold to an American and lost ever since. After a long hunt in Philadelphia we found all three (Figure 2) and they've now been published in an article in the 150th volume of their *Proceedings* which features a woman on its cover. They were proud both of this remarkable discovery and that it had been made in a wonderful fossil collection formed by a woman. Women do not get well written up in history (it is never herstory) - women are not allowed to achieve too much, they weren't allowed on North Sea oil rigs until recently - they assist men and carry the collecting bag. The lady in whose collection these wonderful fossils were preserved deserves better. Her parents thought Etheldred was a suitable woman's name for a start, so a lot of people already thought she was a man which helped! This is not the way to solve

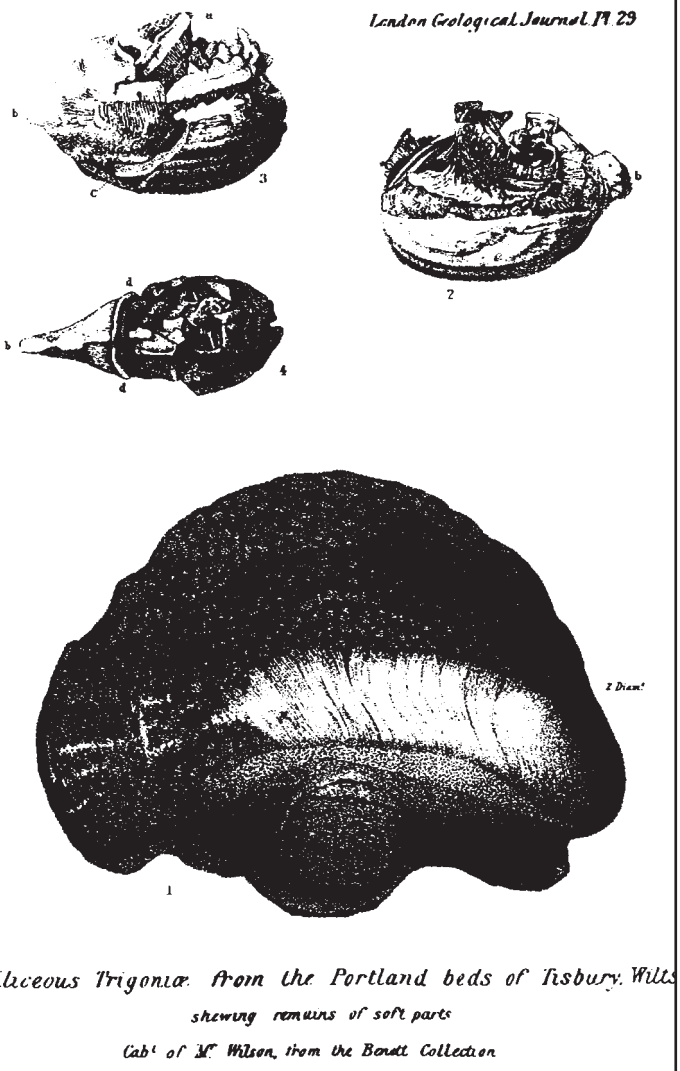
London Geological Journal Pl 29
Siliceous Trigoniæ from the Portland beds of Tisbury Wilts
shewing remains of soft parts
Cab' of Mr Wilson, from the Benett Collection

Figure 2. A finshed copy of Plate 29 prepared for Edward Charlesworth's *London Geological Journal*. This final version was discovered bound into the run of the London Geological Journal held by the Library of the Academy of Natural Sciences. It was originally delivered to Thomas B Wilson from Charlesworth, and given to the Academy by Wilson in 1863. This plate shows two of three specimens of trigoniids from the collection of Etheldred Benett, discovered by Charlesworth to have preserved some of their soft anatomy. (Reproduced $^{3}/_{4}$ size from Torrens *et al.* 2000 p76.)

the problem. I have been delighted to see amongst the students I've taught recently that many of the brightest and best are female. It is nice to see at last that a little more equality is now available (see Thomson 2000).

But I think it's important we historians point out the way in which women have been treated in the past. The Geologists' Association has impressed, they encouraged women from the very beginning when founded in 1858 (Sweeting 1958 p10), unlike the Geological Society of London where women were not admitted until 1919, after so many of their menfolk had been decimated in the World War. History only too well reveals what a struggle it has been to allow women into geology. Etheldred Benett, the woman who found these remarkable fossils, wrote as follows in 1836:

> "They have made me a member of the Imperial Natural History Society of Moscow [having heard of her in Russia] and have sent me a Diploma ... in this Diploma I am called Dominum Etheldredum Benett [I don't know if you did Latin or not, but this proves they thought she was male!] and Mr Lyell told me he had been written to by foreigners to know if Miss Benett was not a gentleman".

People could not imagine that a woman would then be able to write a book such as that she had published in 1831 or would be able to understand anything about Geology. She continued her 1836 letter:

> "I had two letters the same day from the British Museum, one thanking me for fossils [she had donated] as Miss Benett, the other was for my book as Etheldred Benett Esquire, though I gave the Book into the hands of one of the Librarians and told him that it was written by myself, so you see that scientific people in general have a very low opinion of the abilities of my sex" (Torrens *et al*. 2000 p64).

People could not then see that women had any part to play in the remarkable development of geology. I'm delighted to say that things are now changing. So women in geology become my first group of Winners.

But there are many other groups who remain Losers and the history of geology reveals some of these. We must ensure that they don't continue to "lose". One is the amateur in geology, and this may include quite a number of you (it included me when I was first an enthusiastic student of geology). People are amateur when they do not earn a living by doing geology. I was enormously influenced by two; one a hospital pathologist, Fred Stinton (1916-1982) and a world authority on fossil fish otoliths and John Callomon, an academic chemist and world authority on ammonites. In the field of ammonites, there are two remarkable amateurs Callomon and C Willie Wright, who now lives in Dorset and was a civil servant. Callomon and Wright provide much of the international expertise needed for the planned four volume revision of the ammonite volumes of the *Treatise on Invertebrate Paleontology*, one of the most important groups of fossils we have. Only one of these volumes is so far published and says this of Willie Wright (which would be equally true of John Callomon as well):

> "I extend on behalf of all the members of the staff of the Palaeontological Institute [Kansas], our thanks to Dr.C.W. Wright for the unwavering scholarship, dedication to the task, and scrupulous attention to detail that have marked his involvement with the project, and, indeed, his entire career as a specialist on the order Ammonoidea" (Kaesler 1996 pxvii).

Ammonites can, however, be difficult things to understand. In a book called *The Amateur Geologist* we find some professional statements about these wonderful fossils which show that such people do not always know what they are talking about. See what you make of this:

> "ammonites were small animals [rubbish to start with!] that built up their shell by secreting a series of small cham-

bers. As each new chamber was secreted, so the living animal moved into it and lived there until forming the next one. In this way the empty chambers became filled with air and could act as buoyancy tanks rather in the same way as those built into the hulls of modern ships. [Here comes the punch-line]. Each of the chambers became linked by a hollow tube known as a siphuncle, and it was through this that the living creature passed as each new chamber was secreted." (Cattermole 1968 p146).

You try it! Take a deep breath and imagine you are only a small animal but that you have to squeeze through a very narrow tube into your next chamber every once in a while ... it is complete nonsense! This is a professional misleading the amateur. If you want to think more about the real contributions made to geology by amateurs read Hancock (1983) or Torrens (1998). A quotation like the above should make you worry again about the quality of some of the science written up in books, newspapers, articles, or on TV (or especially in lectures like this!). You have to check everything, especially in these politically correct times. In 1991 I announced to a surprised British Association audience in Plymouth, celebrating the 150th anniversary of the invention of dinosaurs there, that it was the 149th anniversary of the invention of something that had nothing to do with Plymouth, but had happened in London. Although I was only a last minute replacement for dear Bev Halstead, at least I had been invited and so did not expect to find myself up against press statements which effectively announced that the British Association was sorry that the person they had chosen to give this 'distinguished lecture' instead clearly did not know what he was talking about. I have taken my revenge since. 'Facts' were on my side (Torrens 1997).

Sadly, amateurs often remain Losers and I'd like to recall some of them to you. One of the most interesting things I have been doing recently is sitting in some sort of judgement on which past British geologists are the real heroes. Somebody had to do the job! It's for the *New Dictionary of National Biography* and we have managed to squeeze in a few people who had been previously forgotten. One was from near Whitby, where Louis Hunton (1814-1838) was born. He was the son of a local alum maker. Alum was produced here in an early chemical process on an almost industrial scale. Aged 21, Louis Hunton read a paper to the Geological Society recording that fossils here had very limited vertical distributions which he documented. His stratigraphic column was several hundred feet thick, from the seashore to the top of the cliff, captioned "a Section of the Upper Lias and Marlstone in a rock cliff near Whitby, showing the distribution of Fossils and the limited distribution in particular of the order Cephalopoda", with the horizons that contain ammonites, demonstrating that these fossils have specific, short, ranges. Hunton seems to have been the first person to have pointed this out and documented it by selecting material collected from the cliffs, not from fallen material. His was an important discovery which enables us to use the limited ranges of fossils to make rather specific statements about the relative ages of rocks (Getty & Torrens 1984). It was during a previous conference at York that I got bored with some of the lectures (as you will have here ...) and went off to the Public Library to try and find what had happened to Louis Hunton. I had tried all the obvious sources but completely failed to find his death registered. There I discovered the poor man had succumbed to consumption and gone to Nimes, France where he died. He was eventually brought back and buried in his local churchyard. If I'd gone to the churchyard first, I might have worked all this out to start with, so the message is plan your research carefully, think about priorities first.

Another amateur in whom I have become particularly interested is Sydney Savory Buckman (1860-1929), born in Cirencester, son of a man who lost his job for espousing Darwinism at the Royal Agricultural College there. This was a place run by the Church of England, where agriculture was God in His Agricultural Guise and Darwinian experiments on the origin of species and the modification of plants through interbreeding were not thought by the management to be part of any Church of England agenda. So the family was forced to move to Dorset, where in 1889 Buckman, aged 29, produced the first of his remarkable papers. In this he demonstrated that the lithology of a rock had no bearing on its age (Buckman 1889). His paper concerns the Toarcian to Aalenian sands which are today called Bridport, Yeovil or Cotswolds Sands. You may have wondered why such sands, which are lithologically identical, still have different names. The simple reason is that their ages are completely different; they are identical in appearance but are quite different in age, younging south. The precision in chronology available from fossils was a crucial break through to which Buckman and an American called Henry Shaler Williams were drawing attention about a hundred years ago, before the discovery of radioactivity. At that time people were saying this was impossible. His obituarist wrote

> "such a phenomenon is now recognised as so obvious a possibility that it is difficult to realise the blank opposition that at first faced this clear example of it" (Morley Davies 1929 plxiv).

This paper was written while Buckman was trying to earn his living as a novelist, but his novels did not sell. This was one of five attempts which Buckman made to earn a living, none of which properly involved geology. But in my opinion he was streets ahead of any professional geologist of his time in the field of historical geology in Britain. His classic paper of 1893 (Buckman 1893) followed (Callomon 1995); he studied ammonites in detail and realised they were subject to very subtle changes over time. He looked at various sections of the same few feet of rock in Dorset called Inferior Oolite and he separated them into up to twelve biochronological units, which he called hemera (as in ephemeral). He showed that in each section some hemera were missing, others were present, some thick, others thin deposits. Each of his sections was a few miles apart and each was different. He demonstrated that by studying the sequence of hemera, you could compare and equate each ammonite bearing rock-unit in terms of its age, with remarkable precision. But it wasn't the precision which proved important, it was the reaction to his paper. J F Blake (1839-1906), who was a Cambridge graduate and later professor of geology at Nottingham, spoke:

> "to call attention to the fact that, though *Ammonites humphresianus* was a large ammonite, its hemera in some of the sections was represented as 3 inches thick, so that any single specimen of such an ammonite would have some difficulty getting into its own zone" (Buckman 1893 p522).

Getting such a fat six-inch thick ammonite into a three-inch bed was something which clearly baffled the best brains. So Buckman

THE TIMES FRIDAY OCTOBER 30 1998
Rock-solid proof that comet killed dinosaurs
Headache: up till now it has been difficult to prove that a meteorite wiped out dinosaurs

Figure 3. "Rock-solid proof that a comet killed dinosaurs!" (Times 30 October 1998)

brought along ammonites which had actually been eroded down to the thickness of their 'zone', the thinness of which was due to subsequent erosion (Morley Davies 1930 p227), it was that simple! Next time you are at the cliffs at Burton Bradstock in Dorset, ponder the diachronous Bridport Sands which outcrop here and how the 'same' sands in the Cotswolds are so much older. Then ponder the overlying Inferior Oolite rocks above them. These are some of the most complex rocks known and I was delighted to have served my apprenticeship as a stratigrapher on them. It was with these rocks that Buckman demonstrated how it was possible first, to be precise about the age of such rocks and second, that it was equally possible to be precise about how very incomplete the geological record was. He wrote (and was the first to make the point):

> "one can hardly view the few feet of Inferior Oolite limestone at Burton Bradstock, about 15 to 20 feet say, and imagine that it represents an interval of time equal to a quarter or a fifth of the whole Jurassic Period - a time during which thousands of feet of rock were laid down [in other places]. But this is because we do not allow sufficiently for the gaps" (Buckman 1910 p.91).

You will all have heard about the K/T boundary bed at Stevns Klint in Denmark. It is a fish-clay, only two centimetres or so of rock. Anybody who's seen such two centimetres of rock should smell a rat! They should realise that it need not have been caused by a simple event. I'm not saying that an asteroid impact did not happen at or near the K/T boundary. I am not saying that what happened in Mexico was unimportant or unproven. I'm saying what is visible in Denmark is very far from being proved to have had a simple connection with anything which then happened in Mexico. This is the sort of journalism we now get: "Rock-solid proof that a comet killed dinosaurs!" (Figure 3)

I don't think anybody has ever found such a dinosaur with a hole in its head! Such rock-solid proof depends on whether you believe that the process is more important than the historical analysis of what actually happened. I think it's what actually happened that is crucial. You need to look at the evidence in each case very carefully and then start to build the picture. If you start with the prediction that a meteorite did hit the earth, and everything then is explained by it, it may provide rather bad science. Stevns Klint to me shows every sign that the fish-rich clay here does not have a single primary, or sudden, cause. It instead shows evidence, just as Buckman claimed, of a rock record full of gaps, of rock which has been highly condensed. Any abundance, whether of fish, clay or iridium, could here in my opinion be largely secondary in origin. That the iridium comes from a largely cosmic source is undeniable, via cosmic dust; it is 'the speed' with which it arrived that is the crucial question. Over a sufficient length of time you could get a thin, entirely residual layer of such material, normal carbonate (Chalk) sediments having disappeared by solution (see Bruns *et al*. 1996, 1997). By such 'normal' processes, involving only great lengths of time, you could get such a thin bed of cosmic (meteoritic), fish, clay, dust preserved on the sea floor and that may be what the fish clay here represents. I don't think everyone is yet agreed about its having a single, catastrophic, impactal, cause. The true scenario may be much more complicated. Multiple iridium spikes are recorded at the other original K/T section at Gubbio in Italy. This is miles away from Mexico and again suggests we are looking at a complicated record. If it had been a single iridium spike I would have more believed it recorded a single event and I might then agree it recorded a meteorite impact. I want you to think. I'm not saying I'm right, I'm just saying that the jury is still out. Buckman had noted that "the amount of deposit [i.e. the thickness of rock] is no indication of the amount of time taken to generate it" (Buckman 1910 p90). Earlier in 1893 he had written that fossil ammonite "species may occur together in the rocks, yet such occurrence is no proof that they were contemporaneous ... their occurrence together only shows that the deposit in which they are embedded accumulated very slowly" (Buckman 1893 p518).

Many such 'sudden events' may be explained just as well by rates of deposition having slowed down or by changes in rates at which past geological materials have been dissolved through solution. Buckman showed that thicknesses bore no relation to durations, yet the geological literature is full of people who have forgotten this. A paper in *Science* 1998 Isotopic evidence for the Cretaceous-Tertiary Impactor and its type (Shukolyukov & Lugmair 1998, which inspired Figure 3) used high-precision mass spectrometric analysis of chromium to confirm the 'cosmic origin' of the chromium. That's fine, nobody doubts the cosmic origin, but did it arrive in a big, sudden, bang, or as a gentle rain over years, even millions of years, which ended up inevitably on the sea floor because it's an inert material which would survive all the solutional processes on its way to the sea floor? The isotopic evidence may indicate its extra-terrestrial origin but it does not prove that it arrived suddenly. Another book by Mike Allaby and James Lovelock, the man who produced the "Gaia" hypothesis, appeared in 1983. This claimed the impact had to have been near Denmark because of the abundance of fish.

> "There can be only one explanation. the fish died where they happened to be, they were in large numbers and after their death their bodies were carried to Denmark by oceans and tides. This is a mechanism which operates today" (Allaby & Lovelock 1983).

In other words there was a simple sudden, mass mortality. I think people can be fooled by the wonderful ability that we now have to measure things. The fact that we can measure and analyse things to the trillionth part does not tell us how the material got there in the first place. The reasons fish can prove abundant in such a fish-clay can be either

a) because the world was suddenly, and primarily, rich in fish (ie sudden death) or

b) fish became all that was left behind as a residual deposit.

The bones of such fish are made of phosphate. Phosphate is a material that resists solution more than calcite and aragonite. So there can be something very fishy about an abundance of fish. Let me try an analogy to make you think. When you go to a crowded church-yard full of gravestones (my example was at Bakewell, Derbyshire where you'll find the grave of the geologist White Watson (1760-1835), you don't suddenly say "oh my God, there's been a sudden disaster here, a catastrophe, look at the evidence of death for all these people". This is because we know that graveyards record a subtle, complex process - people die and they're carried off to this special place where they get accumulated over time. Might they be a better analogy with the fish of Denmark? Did these fish have to have suddenly ended up in one place by disaster there? No, both humans and fish could have ended up in a particular place due to a series of very complicated processes, involving solution, incompleteness and gaps in the record. Bakewell graveyard does not prove a nuclear disaster hit Bakewell.

The next point I want to make is about another group of Losers. These are non-academic practitioners of geology. Academics are a very self-perpetuating group of people - they think that only what they do is important. I don't know how this will change in the future, but I do feel that people who practised geology in the past have suffered in the historical record of geology. The history of practice does not get recorded very well. Just as with Etheldred Benett (marginalised as a woman), John Farey who drew that map at Ashover was marginalised as a practitioner. No-one thought he was important at the time, despite being clearly one of the greatest geologists this country has produced. It was also he who first explained the anticlinal structure of the Weald, by showing that the order of the strata here (Upper Chalk, Lower Chalk, Chalk Marl, red sand, coarse sand, lead-coloured sand down to an Anthill clay) was repeated on both north and south. He didn't know what the beds were in the middle because he had nothing to compare them with (Ford 1967). Farey's teacher was William Smith, supposed father of English Geology, who was another practitioner. He's another of the most remarkable people this country has produced, but there is still no adequate biography of him - five attempts have all failed and this includes me, although I may yet get something done in retirement!

On 24th March 1805 Smith visited a coal boring being carried out at Brewham, near Bruton, Somerset. Those involved intended to find coal here, the "Brewham Intended Colliery" they called it. Their most ephemeral of records miraculously survive in the archives of King's School, Bruton, owner of the site. The school was happy to diversify to raise funds and rented out their fields. The people coal hunting here were struck by the "similarity of soils" to those in areas abounding in collieries, this was claimed as scientific information making the site "most eligible" for such a trial. They dug a great hole, went down six hundred feet but found nothing. Smith arrived after they had gone down only a hundred and twenty feet and the spoil heap yielded him Kellaways Clay fossils which Smith knew proved they had only reached as far as this clay, which lay at the bottom of his Clunch Clay [today's Oxford clay]. The fossil *Gryphaeas* proved to Smith exactly where they had got to in the ordered sequence of strata he had first worked out in the Bath area. They were still so far above the Coal Measures (the only strata then known to yield coal hereabouts) that Smith was able to tell them they were wasting their time. He knew it was unthinkable that they could reach any coal there. They ignored his advice.

This was a red letter day because it was the first occasion in the history of science on which anyone was able to correctly predict that the enormous sums of money then being spent in search of non-existent coal were being wasted. It was a large amount of money, several thousand pounds, enough to explore for a middle-sized oil-field at the present time. The site survives as does the shaft, down which I was told there are two model T Fords, so any time some of you get bored with geology and want to restore cars, we could organise an expedition to dig them out. The coal hunters had been confused by the similarity of the Oxford Clay soils with those elsewhere in Somerset associated with Coal Measures. That these clays look like the clays you find with Coal measures is undeniable, but it was a mere lithology similarity. We now know, thanks to stratigraphy, that there are any number of black clays which look like any other number of different black clays available in Britain. It was Smith's achievement to have been able correctly and accurately to separate them.

So what can we learn for the future? I think the first thing we must do in future is to re-capture the former excitement of geology. I became captivated by this and I'm still delighted that I chose to become a geologist. Roderick Murchison proved how popular it once was when he addressed the populace in the caverns in 1849 at Dudley in the Black Country. Between 15 and 25 thousand people visited the caverns on one day,which proved how popular geology then was. The Bishop of Oxford who was there,took a gigantic speaking trumpet and called upon his audience to repeat after him three times, "Hail, King of Siluria" [i.e. Murchison] (Sweeting 1958 p132). You only get this sort of thing happening to pop stars or footballers (not geologists) today! A Natural History Museum brochure went out in the mid 1990's announcing that they were having to change the Earth Galleries there, because "recent Museum research has revealed that the public's perception of geology is as an academic and rather boring subject of little appeal to the general visitor" (Torrens archives). Next when "Earth Story" appeared on the BBC in 1998, the *Radio Times* put this out:

> "Geology used to be so dull that TV producers would only risk making a programme if there were dinosaurs in it. Or if it was killer geology, with dramatic, terrifying images of the planet in seismic turmoil, exploding mountains engulfing layers of lava and wobbling flyovers with the needle quivering at the top end of the Richter scale ... so [to solve

these problems], to present this new [BBC] story of our Earth, the last thing [sic, geologists having now become things] we wanted was a geologist." (Davies 1998).

I do not think this is true. Geologists are just as able as anyone else to explain the magic and mystery of our planet. But if the BBC thinks this of us then we have most certainly failed. I met Aubrey Manning (the biologist who was chosen instead) at a recent meeting in London and he is a brilliant and amusing fellow. But I do not think his choice has anything to do with why no geologist could be chosen. Why do geologists have such low appeal? This Bill Tidy cartoon from *Private Eye* says the same thing. It depicts a polar exploration in deep trouble, a bit like Captain Scott's, and the caption says "we've eaten the last of the Geologists!" It's very funny, but I think geology deserves better.

'That's it, sir . . . we've eaten the last of the geologists!'
(Courtesy of *Punch*)

Figure 4. From *Punch* (Craig & Jones 1982 p18).

The way to achieve this is to get geology taught more in our infamous, over regulated, schools. How we do that is a question by which I am much exercised.

I'd like to end with some thoughts on how exciting the science of geology can be. This is certainly the impression I get from some of my better students who often seemed grateful to have been introduced to a subject they had never discovered at school. The image I want you to have in your minds is one acquired in Beijing. It is of the (Chinese/Tibetan) North Face of Everest, or Mount Qomalangma (published on the cover of *Episodes* 18, nos 1 & 2, 1995). It was this view that the English first had on their expeditions, before politics stopped them going there through Tibet and forced them to go via India. Since 1995 Everest is now officially 8,850m high - it's gone up 8m because they've got GSS to measure it (*Times World News*, 13 November 1999 internet edition). The geo-science of this place is equally wonderful. It rises 20mm a year because of plate convergence and the summit is moving as well because of faulting, 600mm north-east a year. To be able to measure these with such precision is simply wonderful, but it takes me back to my earlier question of whether we always understand exactly what we're measuring.

The history of this place is also fascinating. The first true geologist here was a Scot, Alexander M Heron (1884-1971) of the Indian Geological Survey. He was the geologist with the British 1921 expedition and was invited to return on the 1924 expedition with Mallory and Irvine. But he had unwittingly upset the Tibetan government "by digging holes in the ground" [geologists do!] who thought that demons would escape through such holes and so he had to be banned from the expedition. He replied:

> "I have to plead 'Not Guilty' to the charge of being a disturber of demons. I did no mining and the gentle hammer tapping [I did, was] insufficient to alarm even the most timid of the [demon] fraternity!" (Firstbrook 1999 p92).

The organisers of the 1924 expedition had little option but to use Heron as a scape-goat and to exclude him from their plans. Those plans of course included Mallory and Irvine's summit attempt in 1924. You have probably all seen the remarkable pictures again first 'published' on the Internet of Mallory's body discovered in 1999. You may have heard mountaineers, including my daughter, rightly wondering if such pictures should ever have been published. I'm afraid poor Mallory has suffered from having been the man who gave that immortal response when asked, why climb Everest, "because it is there" (Firstbrook 1999 p111). I fear that people sought him, and will still seek his companion and their camera, for the same reason "because they are there".

For me, the real hero of the 1924 expedition is another Loser and another person you probably haven't heard of, the geologist Noel Ewart Odell (1890-1987). Raymond Lambert, the Swiss mountaineer wrote in 1954:

> "to all who are familiar with the history of the Himalaya, the effort put up by Odell all by himself, in supporting Mallory and Irvine, seems more extraordinary than the legendary exploit [of Mallory and Irvine themselves who died in their attempt]. The energy expended by Odell during these three days never ceased to cause wonder amongst those who understood what it entailed. Of all those who have attacked Everest so far, Odell, the geologist, was, I believe, the best equipped" (Dittert *et al*. 1954 p150).

Other problems for geology emerge from the Himalayas. The Chinese understood the importance of understanding the stratigraphy when they made their second ascent from the Chinese side in May 1975 (Chi-Hsiang & Shih-Tseng 1978). No British climbing expedition has apparently yet taken a geologist to the summit (Searle 1999), just as the Americans didn't think a geologist was worth taking to the Moon, until Harrison Schmidt went along on the last Apollo trip as a token gesture. How on earth [sic!] can you explore a new planet or heavenly body without taking a geologist? We in the west have failed to get our message across. The Chinese understood this better, and on their second 1975 ascent they included geologists, who found the summit limestones were crystalline Everest limestones above the Yellow Band. They identified these as Lower Ordovician rocks of Arenig-Llanvirn age. They were able to be precise about the age of these rocks by using fossils, collected nearby by geologists who happened to be mountaineers.

This Chinese work cited that of a geologist from India called Viswa Jit Gupta (born 1942) of the University of Chandigarh. He has since been exposed in the pages of *Nature* and *Science* from 1989 for systematically fiddling palaeontological data into his 450 papers published over 25 years. His Himalayan records are simply salted with fossil material which came from New York, Oklahoma, the Universities of Aberystwyth and Paris, Morocco

and Italy; stolen from teaching collections or bought from dealers, and then purported to have come from the Himalayas. Gupta was exposed when these fossils were examined by other palaeontologists. One of the most astute observers was the French palaeontologist who wondered how such greasy material could claim to have come from some of the freshest, most untouched outcrops on Earth. They had instead come from a teaching collection at the University of Paris and were greasy from student hands. John Talent, the Australian who exposed him, has pointed out how between 1965 and 1990:

> "a cornucopia of disinformation was poured into the geology of the Himalayas ... Clearly, in view of the irregularities in Himalayan geology identified here, a major exercise is necessary to delineate just where reality and truth might lie. Until the facts are established it would seem advisable to doubt the rigour and even the factual content of any work bearing the name of V J Gupta amongst its authors" (Talent *et al.* 1990 p582).

In other words, these rocks have been the systematic victim of one of the worst scientific frauds this planet has ever seen and not just in geology. I'm sad this case is not better known and, even worse, I'm sad that his University should still employ him in India.

My final question returns to, how do we get geology more popular? Everywhere I go I find enthusiasm to learn more about geology. We've just had a reunion of old Keele students - they must have heard I was leaving - and 180 of them turned up. My daughter, who's a doctor, was amazed to see people so grateful and proud to be part of the same tradition that brings us all together here tonight. The fun of Geology, in lab or field, is a wonderfully unifying subject. May it long continue. H H Read (1952) asked:

> "how is it that the pleasures [of geology] that cost so little, and that need no special equipment..., are not eagerly followed by all or, at least, by more? The reason is to be sought in the lopsidedness of our education. Geology is a cheap subject which requires a minimum of apparatus and equipment. Its matter is available without cost in the immediate neighbourhood of every school, and it has a free laboratory in full operation in the surrounding countryside. Geology is the most cultural and truly educative of all the sciences. But we find that geology is taught in very few schools. Boys and girls are completely ignorant of the fascinating story of the very stage on which they will spend the rest of their lives.... If they had acquired even an elementary geological knowledge at school they would have been furnished with an interest expanding with experience" (Read 1952).

I couldn't agree more with that. We shall need geologists more in the future as energy crises face us. A graph of energy consumption in America, from 1800 to 2000 shows the depletion of wood, coal, oil, and natural gas and the very unsure future of nuclear power. All of these problems are going to continue into the future. When the oil starts to run out in about 2015, what's going to happen? We're all now moaning only about the price of petrol. Conservationists point out that to increase the price of petrol is the best thing to do, as it forces us to find alternative means of getting around. Thinking about other future needs, we are going to need to find much more water, even in places like Lake Torrens - my students were impressed that the sixth biggest lake in the world is both apparently named after me and never has any water in it! But in 2000 Lake Torrens and nearby Lake Eyre were full to the brim for only the third time this century because of something that has happened, probably global warming.

We will also need to solve the problems of pollution. My undergraduate mapping area was in Skye. Its beautiful peaceful beaches are today flooded with marine rubbish. People try to clear it up but the fact is that the British are among the worst recyclers on the planet. The economics of recycling are as complex as everything else, as I urged during this lecture. Then I had just come back from Freiburg, Saxony. Here 80% of all glass rubbish is recycled - in Britain it is 27%. In Switzerland 52% of all waste is recycled, we achieve only 9% in Britain. This is another thing we have to do something about.

Finally we have to do something about bureaucracy and managers. Bureaucracy strikes me, and many others involved in public service, hospitals, schools or the law, as a corrosive activity which is destroying much of the innovation and many of the most original people in the country. We've got to stand up and be counted and I'm standing up to be counted here. Firstly it confuses; research and development are not the same thing. Sir Richard Doll (the man who proved how dangerous smoking was and saved a lot of lives, although it was much too late for some) pointed out:

> "basic research is not the same as development. A crash programme for the latter may work, but to try it for the former is like trying to make nine women pregnant all at once, in hope of making one woman have a baby in one month's time".

Secondly, it encourages us to lie. My former University appeared in a top ten list of universities for some feature (I don't know what it was, it might have been something quite mundane, it certainly wasn't scientifically tested). Within days a press release went out in 1997 from our press office saying:

> "Keele University is one of the top ten universities in the country. At this very important point in its life, Keele seeks to appoint a talented and motivated Media & Publicity Officer to join its PR Team" (Torrens archives).

I still don't believe this claim. But my best example comes from America, where many best examples come from. A University of Wisconsin pamphlet of 1967 claimed (and I learned from your laughter that you were better informed about American geography than my students)!:

> "the location of the University of Wisconsin is ideal for modern Oceanographic studies since it lies mid-way between the Atlantic and Pacific Oceans" (Craig & Jones 1982 p19).

Thirdly, and this I think is worst of all, bureaucracy restricts. Francois Ellenberger, a French geologist whose funeral I attended in Paris earlier this year, wrote in 1992 of

> "the disappointments of life; one of which was to see in the course of years the strictures of academic bureaucracy progressively strangling our profession [geology], and inhibiting the freedom of research. Woe to him who does

not submit to a group, whose programme is assigned by these people who always know better, and who, in their omniscience and omnipotence claim to direct the paths of research. Now one is forbidden to work in more than one speciality and today, [even] Charles Darwin would be in serious trouble" (*Geoscientist* Vol 2, p 31- his speech on receiving the Friedman medal).

Our friends, the Taylors from the real OU (Oklahoma University) and my wife and I spent the rest of the day of this lecture following in Charles Darwin's Salopian footsteps, he had Staffordshire connections, his wife was a Wedgwood, he was born here in Shropshire and he is one of the greatest people from this part of England and part of its traditions. I agree that he would be in serious trouble today, if he was an academic. Would he be categorised as a biologist, an oceanographer, an evolutionist, a geologist or a palaeontologist? He would have to be only one, the 'system' now demands it. To work in more than "one unit of assessment" is assumed to mean one does both (or all) badly (much the same as my lecture?). When I tried to be both geologist and historian, my University said it "diminished" both! A writer to the *Times* on 3 June 2000 hit the nail on the head, and I end by quoting this:

> "the incessant pressure on resources, the dispiriting and often counter-productive assessments of every facet of the academic machine, the archaic state of teaching and laboratory provisions, the need to maximise student numbers, and the scandalously low pay of intellectually brilliant individuals all conspire to drive much of the university sector towards mediocrity and depression" (*Times* 3 June 2000).

These are exactly the reasons why I left University employment. As I said, I trained as a geologist, and will always be one, but I have also a real interest in history, whether of the Earth or of the people who have studied it, but I was banned by bureaucrats from being both historian and geologist. I worked at the one British University where every student had an "and" in his or her joint honours degree title, yet similarly minded academic staff teaching them proved unthinkable. I was told that for me to use the word "and" in whatever I was calling myself would be to "diminish both activities". I think we should fight back against such madness. I urge on you finally the words of another Salopian Loser of whom we should be more proud. Robert Townson (1762-1827) wrote three of his books in a village not many miles from here, just north of Church Stretton, using the same resources (the library of Shrewsbury School) that Charles Darwin later used. He had travelled in Hungary and one of his books was about Hungary. My wife and I were privileged to be part of a conference there in 1997 which honoured him. It then took twenty-four academic 'specialists' to analyse the work that one man had achieved there in three months, so wide were his interests. On the 5th of May 1793 Townson wrote:

> "reached a village called Oberrechsdorf; where, as I expected, I met with very bad fare. My attempts to persuade the landlord to put on clean sheets were all in vain: he said he could not always be putting on clean sheets. I took my revenge and slept in my boots" (Townson 1797 p34).

We should all sleep in our boots a lot more....

Acknowledgments
I am grateful to Rosemary Darby who faithfully transcribed the tape and to Jane Clarke who edited my sometimes outspoken talk in July. This paper has been edited from these versions, trying a little to keep the immediacy of the spoken word.

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Book reviews

Extreme Environmental Change and Evolution by Ary A.Hoffmann & Peter A Parsons, 1997, University Press, 259pp, £19.95 (paperback) ISBN 0521446597.

As may be apparent from the title of this book it 'leans' more to biology than geology. However, this is not to say that it doesn't provide some interesting reading. Much of the material has previously been presented to third year undergraduates in biology with several of the chapters having been used at Honours and postgraduate level. The authors' aim is to 'provide a book that is both useful in teaching and of general interest' – whilst I'm sure it will be useful in teaching I think the word 'general' here refers to a fairly astute scientific audience!

I found some of the chapters fairly 'dry' and somewhat heavy going but will be the first to admit that biology isn't my strongest subject. Those of you who shy away from maths, beware of the smattering of statistical analysis and matrices; however, the judicious use of graphs certainly helped to bring the subject across.

The book is broken up into 7 chapters listed below in order to give a better 'flavour' of the subject matter:-

Chapter 1 – Introduction; Chapter 2 – Variation and Extreme Environments; Chapter 3 – Natural Selection in Extreme Environments; Chapter 4 – Limits to Adaptation; Chapter 5 – Evolutionary Outcomes: Comparative and Optimality Approaches; Chapter 6 – Extinction, Diversification and Evolutionary Rate; Chapter 7 – Conservation and Future Environmental Change

It's not the sort of book that I would recommend reading cover to cover but dipping into the various chapters will provide the reader with some very thought provoking topics. In particular chapters 6 & 7 were very readable in their own right, with chapter 6 possibly being of greatest interest to the die-hard geologist. This chapter considers the effects of environmental change over geological time scales as monitored from the fossil record.

So, who is this book for? Well, anyone studying Evolution should already be aware of the title and would find the book useful as additional reading. Also, the evolving theme of 'Earth and Life' within the OU, currently S269 and coming your way soon S369, means that the book has a much wider 'Earth Science' audience.

Allan Hale, Continuing ES student

Discovering Geology: FossiI Focus - Plants by I Wilkinson, 1999, BGS, A3 folded, £1.95, ISBN 0852723237.

This booklet, written by Ian Wilkinson for Earthwise publications, is a very easy to read and attractive publication with both colour illustrations of plants in their natural environments and clear, colour photographs of plant fossiIs.

The reader is given a general introduction to the major evolutionary plant periods placing them within the geological time-scale, with an illustration showing how and where the main types of plants (giving both their fossil and biological names) in this period would grow. This is pulled together by a very easy to read time-scale diagram.

There is also a section of extra, anecdotal snippets of information about fossiIised and Iiving plants. This booklet gives a good introduction to fossilised plants and would be particularly suited to a beginner to kindle further interest, and at £1.95 would be a good investment

Wendy Owens continuing Earth Sciences student

Frontiers for Mineral Exploration in the Third Millennium

Chris J Carlon, BSc, PhD, Anglo American plc, London

Introduction

As we enter the new Millennium, society continues to advance technologically at a surprising rate, and with that advance is the ever-increasing demand to supply a greater variety and greater amount of minerals. Minerals are required for the metals and elements they contain, or their physical and chemical properties as the raw materials for industrial products.

Minerals support modern society and we could not live without them, but do we realise just how many metals and minerals we use? Does the average 'man or woman in the street' make any connection at all with the metals their car or bicycle is made from, and holes in the ground from which minerals are dug? (Figure 1)

Figure 1. The Kennecott Bingham Canyon open-pit copper mine, Utah, USA, one of the largest open pit mines in the world.

Metals are currently mined from low latitude deserts to the high Arctic, and exploration for new resources also takes place in these extremes of landscape and climate. Mineral exploration is therefore a worldwide activity involving many thousands of companies and individuals.

The Industry

The mineral exploration industry, intimately linked to the mining industry, invests around US$3-5 Billion each year in the search for economic mineral resources. This investment fluctuates with economic cycles, and in 1999 with the industry in recession it sank to US$2.7 Billion.

This cyclicity produces a 'bust and boom' industry where periods of reduced exploration spending have been followed by exploration booms, usually fired by a particular commodity such as copper in the 1960's, nickel in the 1970's, gold in the late 1980's and early 90's. When that happens geologist' respond rapidly and successfully and it is not long before diamond drill exploration rigs start hitting new mineralisation.

Mineral exploration is a very high risk activity, and today it involves considerable intellectual and physical effort not only to locate useful metallic and industrial minerals, but minerals in sufficient quantity that can be mined, separated from waste rock and concentrated profitably so as to constitute an ore.

Modern exploration is far more complex than it used to be. The prospectors who panned millions of ounces of gold from rivers in California, Alaska, Canada and Australia in the 19th century knew that "gold is where you find it" - we can now be a little more specific.

Ore bodies are natural accumulations of metals and minerals resulting from geological processes working interactively which lead to mineral formation, concentration and preservation. This situation is rare and the generally held opinion is that on average only one discovery will result from the examination of 1,000 exploration properties, and only one mine will result from every 100 discoveries. With a success rate of one in every 100,000 prospects the chances of finding an orebody are slim, but exploration geologists are realistic optimists and have increasingly more tools to apply to the task.

That task is best described as a commercial activity in which geologists engage. Exploration is about creating wealth, for the exploration-mining company, for its owners and shareholders, and for the host country by way of foreign investment, taxes, royalties, employment and the generation of secondary industries. To generate this wealth involves high-risk expenditure, for a mineral deposit in the ground is worthless unless investment can exploit it.

Exploration Methodology

All exploration companies start with a defined strategy to search for a specific commodity or to investigate a certain area, terrain or country. They can then proactively seek out and buy into an existing project through a joint venture or commence a sequential exploration programme, which generally passes from regional to specific. Regional programmes can be as large as millions of square kilometres, but the objective is to rapidly reduce this area to a much smaller target size. Holding exploration ground by licence can be a major expense, so large regional exploration programmes are often desk studies prior to licensing.

Projects pass from reconnaissance to target exploration, first recognising then defining and evaluating a target in two dimensions before pitting, trenching and drilling to define the third dimension, volume, tonnage and grade. As targets are defined costs increase, and a typical programme can cost 1-2MUS$ per year until drilling commences when costs rise rapidly (Figure 2).

Figure 2. Diamond drilling in the Middle East.

Where to explore can be governed by many factors, such as company strategy, prospective geology, stability of the government and security of the investment environment.

Prospective geological terranes often cross international boundaries, and must be evaluated not only in terms of technical potential for the minerals being sought but also with regard to political stability, economic, legal, fiscal, commercial, environmental and sociological criteria. There are currently an estimated 100 countries trying to attract foreign exploration investment. This is around a 50% increase since the late 1980's and the end of the Cold War, but many of these countries have prohibitive tax regimes and unattractive commercial and mining legislation. Countries which are highly prospective can be legally, commercially and fiscally totally prohibitive and, as large investments are required, stability and security are all-important.

Minerals are unevenly distributed around the globe but certain geological terranes can be defined which may thus be highly prospective for mineral commodities. Examples of these terranes are the Andean Province for copper, the Basin and Range of the western US for gold, Archean cratonic areas for diamonds, and carbonate basins for lead and zinc.

Prospective terranes can be defined by inferred lithotectonic settings such as island arcs and back-arcs for massive sulphides. They can also be defined by age (e.g. Proterozoic base metal deposits), or more specifically by the occurrence of known mineralisation. Mineral occurrences in a terrane can be used empirically to predict occurrences in a similar setting elsewhere, thus the occurrence of diamonds in South African basement hosted kimberlite bodies was used as a model to successfully find diamonds in Siberia and more recently in NW Canada.

This also helps to predict where a certain commodity is unlikely to be found, such as diamonds here in the West Midlands - although always expect the unexpected in exploration! This predictive element will be referred to again later.

Company strategy, market demands or predicted demands, commodity value and the needs of society all dictate which commodities are to be sought. Historically mines were gravel workings in streams and rivers that led to the discovery of vein deposits, typically for gold and tin, but also for copper, lead and zinc.

With increasing demands from society new minerals and metals have come into use, such as borates, the platinum group metals, and the technological metals titanium and aluminium. Some 50 or more main commodities are now sought in igneous, metamorphic and sedimentary rocks of all ages in cratons, fold mountains, rift basins, stable platforms and volcanic arcs world-wide.

With this explosion of potentially economic resources and ore types, exploration has become far more complex and the techniques have become very sophisticated.

Exploration proceeds through the application of geological and exploration models (the ideas) and the application of science and technology (the methods) to detect anomalies due to mineralisation in the target terranes (the places). Together these three comprise what can be regarded as the frontiers for exploration so how will these advance in the Third Millennium ?

The Three Frontiers

The evolution of exploration has included not only the application of science and technology but also ideas generated in one place, which were then applied in another. Prospectors through the ages have panned streams and searched for grey-white gold bearing 'ledges' (veins). They recognised colour anomalies, searched for oxidised 'gossans' and identified poisoned ground. This knowledge grew and was applied as new frontiers advanced beyond the historic and ancient mining areas to new frontiers in Africa, the Americas and Australia.

As noted before, Siberia opened up in modern times with the discovery of diamonds in the late-1800's, and the Wild West of the US with gold and silver mining in the mid 1800's. The discovery of the great Broken Hill Pb-Zn-Ag deposit in NSW Australia led geologists to investigate a similar terrane in Northern Cape Province South Africa which discovered a Broken Hill lookalike in the Gamsberg-Black Mountain area.

The interaction of empirical observation built up models for exploration which were applied in new areas. This process has continued but is ever more complex.

The Geographical Frontier - the Places

In the last decade vast areas of the world's surface have become accessible to western companies and foreign investors. Many of these areas have not been investigated by modern exploration methodologies and are classic cases for applying old ideas in new areas. Many of these areas possess reasonably good exploration data sets, but the very nature of the political system stifled innovative exploration both in theory and practical application.

The collapse of communism led to this opportunity in the Former Soviet Union, opened up Central Asia, Eastern Europe and parts of Africa. Similarly, while politically stable, a country could become attractive by removing or reducing onerous tax and royalty rates, or drafting new mining legislation. This has happened in Chile, Greenland and Sweden with very positive effects on exploration investment.

Socially, exploration has been affected by the demands and actions of minority cultures such as the Sami in Norway, the Aboriginals in Australia and tribal groups in SE Asia and Central America. Political unrest in parts of Africa, South America, the Middle East and even Europe has changed the exploration map.

Mineral resources in the ground are worthless unless developed, and the geographical frontier will continue to evolve as countries become more or less attractive either technically by the application of new ideas, or politically and commercially by encouraging or preventing foreign investment.

The Geological Frontier - the Ideas

This continues to grow with the detailed understanding through research and discovery, of old established and newly discovered ore deposits. The origin of hydrothermal fluids, fluid flow, fluid mixing, the sources of sulphur and metals in solution, and the reasons for mineral deposition are becoming much better understood and are generating new ideas.

The application of a new idea, especially in 'old' areas already known to be mineralised, has led to the discovery of many new deposits in old established mining districts and some spectacular discoveries have resulted.

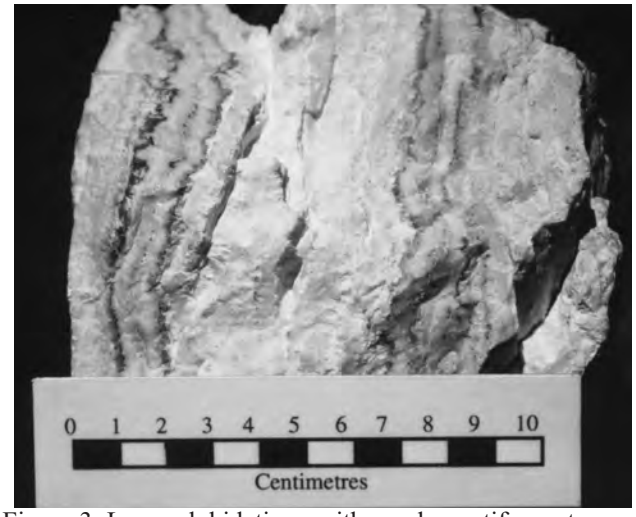

Figure 3. Low-sulphidation, epithermal, crustiform structured gold vein mineralisation, Taseevo Mine, SE Siberia.

These new ideas relate to the understanding of empirical exploration models.

Empirical ore deposit models have been responsible for the discovery of major resources in many parts of the globe including Siberian and Canadian diamonds, base metal massive sulphides in Canada and Scandinavia, zinc in Ireland, copper in South America, zinc-lead in South Africa and gold in SE Asia.

Some models are well established and well understood such as porphyry copper and copper-gold, carbonate lead-zinc, epithermal precious metal (Figure 3), volcanogenic hosted massive sulphides, 'shale-hosted' or 'SEDEX' lead-zinc, lamproite and kimberlite hosted diamonds. However, there are always parochial variations and many deposits do not yet fit any known models, the so-called 'unconventional' ore deposits.

New models are constantly being refined and defined such as lateritic nickel, FeOx-Cu-Au and mobile belt diamonds, and new models will undoubtedly be generated.

The Technological Frontier - the Methods

The application of science in field geology, geophysics and geochemistry is the practical side, the 'going out in the field and exploring'. This aspect of exploration has steadily advanced by applying geological, geochemical and geophysical techniques both on the ground, and increasingly from the air in airborne and satellite-borne remote sensing.

As technology has advanced the methods have become more sophisticated, the data collection improved, the precision increased and the resulting evaluation enhanced.

Gabriel Plattes in 1638 in his book "A Discovery of Subterraneall Treasure" indicated that with the use of a divining rod - a 'Virgula Divina' you could find mineralisation where it gave the 'strongest signes'. However, he was already nearly 100 years out of date! In 1555, Georgius Agricola, one George Bauer, a physician in the town of Joachimstal published 'De Re Metallica' describing the mineralisation, exploration, mining, mineral processing and smelting techniques then being used in the Bohemian Massif. He noted that "there are natural indications of veins" - and you don't need twigs for divining.

Nearly 450 years ago it was already known that metallic mineralisation was an unusual concentration of relatively rare elements, which as a consequence affected the local geological, geophysical and geochemical environment, often creating an anomaly many orders of magnitude larger than the mineralisation and thus easier to locate.

Field geologists still search for geological anomalies using standard field techniques but are now assisted with technological additions. Accurate location is derived from a satellite geographic positioning system and maps produced from satellite images. Not only topography but also geology, structure and even remotely sensed rock alteration features possibly indicative of mineralisation can be mapped, and those maps carried into the field to aid ground follow-up.

Remotely sensed reflected and absorbed visible light in the blue, green and red spectra, together with near infra-red, short wave infra-red and a mid-infra-red thermal spectra can be used in various spectral combinations to identify not only different rock types, but also iron, clay mineral and carbonate alteration. This technique is particularly suited to major deposits of copper and gold associated with granite-porphyries, hydrothermal vein systems and associated silica-clay mineral alteration patterns. Such targets can be detected without even going on the ground, and rapidly lead exploration geologists to potential sites of mineralisation and discovery.

This technique is being enhanced by hyper-spectral scanners which are capable of collecting a much greater number of spectral bands. Visible light (blue-green-red) near infra-red, short wave infra-red, and thermal wavelengths are being collected, and the advanced mathematical evaluation and computer imaging of such collected data will greatly improve remote targeting of potential mineralisation.

Digitally captured, computer enhanced 3D topographic images or digital terrane models (DTM's) present very graphic representations of the earth's surface topography. These can be shaded by a rotating sun effect, can be used to define structure or to provide a layer upon which surface geology and exploration data can be 'draped'.

Thematic Mapper satellite scenes obtained from the Landsat 5 satellite are useful for field location, constructing geological maps and structural interpretation. They can be used to identify major fold and fault geometries, detect the sense of movement along faults, identify zones of extension, compression and shear and indicate areas of low strain. Such remotely sensed data and interpretations can indicate where mineralising fluids might focus and precipitate hydrothermal mineralisation.

Structural features can be digitally defined and superimposed on the image together with other data sets such as mineral occurrences to target areas for ground follow-up.

Technological advances in geophysics are producing ever more sensitive instrumentation for measuring the earth's magnetic, radiometric, electromagnetic, gravity, electrical and seismic features around and caused by the presence of potentially significant and economic mineralisation. Surveys are conducted on the ground but increasingly are being done from the air. Gravity measurements, previously measured only on the ground, can now be measured by a gravimeter in an aircraft, greatly reducing the time and cost of a regional gravity survey.

With the generation of greater volumes of much more precise and accurate geophysical survey data, technology is also advancing in the imaging of these data.

Older analogue geophysical data can now be captured digitally from black and white contour maps. Digitally enhanced, colour coded and 'sun shaded' data give a much better clarity and makes these data far easier to interpret. Enhanced geophysical techniques, together with geology and geochemistry, are improving both the targeting of ore deposits and an understanding of the origins and features of mineralisation.

Geochemistry is the systematic sampling of a medium, be it stream sediment, soils, overburden, bedrock or biological material, to identify patterns of element concentrations to home in on potentially economic mineralisation. Geochemical exploration has been used successfully in the discovery of many major ore bodies and is an exceptionally useful technique, both for rapid reconnaissance as in stream sediment sampling or more detailed target definition using 3D element distribution patterns in bedrock around mineralisation.

New advances in geochemistry include the analysis of gases emanating from the bedrock, and the development of ever more precise techniques with ever increasing lower limits of detection through parts per million to parts per trillion. As with geophysics results are now subjected to advanced image analysis.

Vivid colour and shaded images or data layers can be created and viewed interactively by computer to detect anomalies by visual and mathematical spatial recognition techniques using numerous layers of data. These techniques are referred to as Exploration Data Integration, and seek to identify spatial anomaly patterns in geo-referenced, co-registered multiple exploration data sets to enhance target identification. The process is greatly enhanced by geologists, remote sensing geologists, geophysicists and geochemists working together to define targets.

Conclusions

So into the Third Millennium the future for exploration is exciting:

In the Frontier of Geography - There are new areas to explore, some for the first time with modern exploration techniques and technology.

In the Frontier of Geology - There are new ideas and ore deposit models being generated.

In the Frontier of Technology - There are new methods in remote sensing, data analysis and computer aided imaging and interpretation.

However, exploration geologists still have to ground truth potential target areas and properties. They still carry hammer and hand lens, but this is now supplemented with a GPS receiver, and possibly a portable infra-red mineral analyser to ground check remotely sensed spectral mineral anomalies. In the evening they may retire to the field camp, very often a tent, with a laptop computer and satellite communication links to fax, 'phone, e-mail and exchange data from ever more exotic locations to a central base across the world.

These are the frontiers for mineral exploration as we enter the Third Millennium, and they will continue to be pushed forward for however long society needs its vital mineral supplies.

Book reviews

Geology of the Glasgow District by H S Hall, M A E Browne & I H Forsyth, 1998, BGS, 117pp, £45.00 (paperback) ISBN 0118845349.

If you are wondering what to buy a geologist for Christmas, birthday or at any other time; if you are visiting or leading a field trip to the Glasgow district; if you are an armchair geologist or a geology student, then I recommend a copy of the British Geological Survey memoir on the Geology of the Glasgow district. This (soft-cover) book provides a detailed description of the geology written in simple, straightforward terms. The book is illustrated with a wealth of diagrams, maps, charts, cross-sections and photographs. The authors guide the reader through each period of geological history. There is also a section on geophysics and one on economic geology. There is something for everyone. At £35 it is good value and one of those books you may want to have in your library.

Ron Whitfield

Age Determination of Young Rocks and Artifacts by Gunther A Wagner, 1998, Springer Verlag, 466pp, £57 (hardback) ISBN 3540634363.

Although this is a comprehensive study of dating methods using physical and chemical clocks for Quaternary Geology and Archaeology it is set out in a way that makes it interesting for a more general readership. It examines a whole host of "clocks" based on a measurable rate of change since it first started ticking. Each of these chronometric techniques is first described and then examined in detail for practical usage and limitations, using case studies in the respective fields. Many of the techniques, such as "particle track accumulation" are new to me, a layman, but then some have only been developed in the past 3-5 years so the book is up to date with current science. Indeed, the author's intention is to bring all of the current methods of dating together in one reference volume. After a brief introduction covering the physics of radioactive decay and the maths involved in calculating error and precision, the succeeding chapters deal with the materials that might be examined, from impact glass to glacier ice and their properties that can be used to determine their age, or that of associated artifacts. Each dating method is then comprehensively detailed. I found that the practical aspects of each method would be useful for laboratory based research, whereas the methodological basis and application is of more general interest. For the OU student of Geology the book would be a useful reference, particularly the chapters covering Paleomagnetism and the Earth's Orbit & Climate change.

George Raggett BA Open

United Kingdom Minerals Yearbook 1997 by J A Hillier & D E Highley, 1998, BGS, 87pp, £35.00 (paperback) ISBN 0852723091.

This book is well summarised in the preface by the director of the British Geological Survey, Dr David A Falvey. He writes: "Government and Industry alike require access to reliable sources of data on minerals and the minerals industry in Britain. Such data are provided in the annual BGS publication United Kingdom Minerals Yearbook. The yearbook brings together in one volume, data and authoritative commentary on some current developments in the minerals industry. It is of value to all those interested in the many facets of Britain's mineral industry and its contribution to the national economy, and forms part of Britain's continuous mining and quarrying record. The Yearbook is underpinned by a comprehensive data archive which is available for consultation." The Yearbook is written in simple terms and includes a wide range of charts, maps and spreadsheets. It provides interesting reading for amateurs, like me, as well as those with a more in-depth knowledge. If you are researching minerals I expect it will be compulsive material. If you are interested in applied geology then it is a good source of information with lots of "wow, I didn't know that" sections.

Ron Whitfield

Partnership – the way forward in a big World

Ian A Thomas, Director of the National Stone Centre (NSC) and Chair designate of the Earth Science Teachers' Association (ESTA)

I begin on a personal note and make no apologies as I hope this will help to illustrate my particular stance. I studied a wide range of disciplines at 'A' level and my early university years, ranging from art to physics and chemistry to cartography (see appendix 1). In studying these subjects, I was fascinated by interrelationships; art (in the form of landscape painting), geology and cartography are obviously inter-linked. I come from a family traditionally engaged in art, nineteen once took part in our own family exhibition which received good reviews in the Welsh press, yet our collective predominant degree subject areas are in languages and science. My own interest in geology also stemmed from a former family ownership of Parliament Quarry, Mansfield Woodhouse, Nottinghamshire, which before their involvement supplied stone for the rebuilding of the Houses of Parliament in the 1840s, and from schoolboy investigations of lead and copper mines in Cardiganshire. In effect, industrial archaeology and a love of landscape led me to study geology and I am still able to combine all three in our design work at the National Stone Centre (NSC).

My starting point is therefore that, for geology to progress and appeal as a science, a broad view is vital. Such a position is not new.

Scientific Bodies

Founding Dates

Royal Society 1660

Geological Society (of London) 1807
Earth Science Teachers Association 1967

Physical Society 1874
Institute of Physics 1922

Institute of Chemistry 1877
Royal Society of Chemistry 1980

Association for Science Education 1901

Institute of Biology 1950

Figure 1. Founding dates of professional institutes.

In the early nineteenth century, geology was regarded at the forefront of science, indeed the overarching science (Figure 1). The Royal Society was born in 1660, with an all embracing brief covering science and engineering; however, the Geological Society of London was one of the first major learned bodies devoted to a specific scientific discipline, founded as it was in 1807. Early membership included many of the key scientists of the day. The next 30 years saw early detailed geological maps, culminating in the establishment of the first ever national geological survey in 1835.

This interest by the cognoscenti was driven not only by the quest

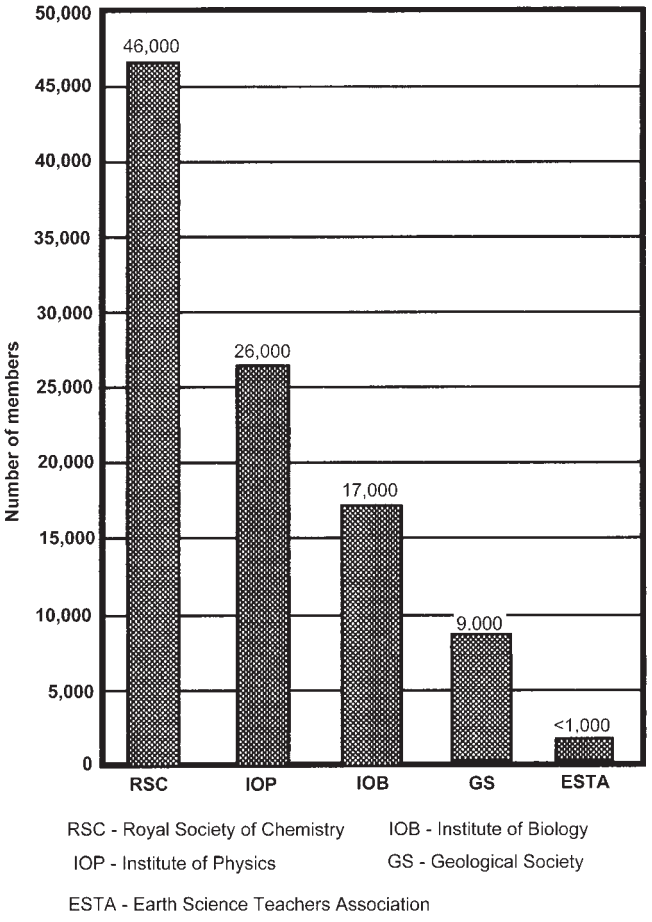

Figure 2. Institute membership numbers.

for scientific advance but the growing awareness of the significance of geology in the creation of wealth through mining and quarrying minerals to the building of ports, canals, railways, roads, reservoirs, all vital to communication and a steam driven economy. Hugh Torrens covered this theme superbly in his keynote lecture for this symposium and Stuart Smith developed this further by reference to practical presentation of the evidence.

Over the last century and a half we have seen a clearer distinction being drawn between what are now considered the mainstream sciences, but some of this differentiation emerged surprisingly late in the scheme of things.

In the last 50 years, two further trends have developed; the three 'big' sciences have grown considerably in status, as reflected by the membership numbers of the main institutions (Figure 2).

In parallel, within geology, a whole raft of sub-disciplines has developed, palaeontology has long been with us (is it even a sub-discipline of geology?), and virtually all are hybrid subjects: geochemistry, geophysics, engineering geology/geotechnics, economic geology are the obvious ones, geobotany, palaeo-ecology and also, over the last 10 years, geoarchaeology and medical geo chemistry have become significant, particularly with advances in

geo-data handling. To some working in 'core' geology, this is perceived as fragmentation, but to others it is considered to be a stimulating and broadening experience – applied geology in its widest sense. However, as Hugh Torrens has hinted, few classic polymaths would survive in this climate.

Take any voxpop reading, dinner party or a pub discussion and one could almost guarantee that as soon as others learn that you are a geologist or studying geology, the conversation will turn to the excavation of a Viking long boat by Tony Robinson's Timeteam or a project to rebuild the pyramids in Hemel Hempstead, or at best the thawing out of woolly mammoths. The level of confusion between archaeology and indeed astronomy on the one hand and geology is far reaching. Yet the thirst for popular geology is considerable, if unfocused. Indeed the general popularity of geology is beginning to outpace the mainly arts-based TV programme making community and certainly those framing the National Curriculum largely conditioned by the 'three big sciences'. Take a simple example. When the National Curriculum Science curriculum was introduced in the early 1990s, earth science was a small but relatively distinct component alongside the 'big three', albeit they all were coded under other, 'softer' names. Despite the groans of primary school teachers having to teach science formally for the first time, many considered that one bright spot was the use of fossils as a means of motivating pupils, especially boys. Then at a stroke, the round of streamlining in the mid 1990s removed the reference to fossils, despite howls of protest from geologists and non-geologists alike. Although fossils can be covered obliquely by referring to conditions for growth in Key Stage 2 (junior school), the subject is only specifically introduced virtually out of the blue in Key Stage 3 and that is without any attempt at progression. Yet we see that 'Walking with Dinosaurs', for all its scientific imperfections, was the most popular UK TV science programme ever with 18.9 million viewers, ranking 19th in the all-time league of UK TV programmes. Sticking to non-fiction, in its own way 'Earth Story' was also highly popular, even if a little heavy going for some. Blockbusters such as 'Armageddon' and 'Dantes Peak' portray geologists in an heroic or positive light and are at least a little more scientifically informed than the 'Flintstones' and 'Godzilla'! (Nield T 2000).

A measure of the modification of 'informed' public perception (although still a little shaky) can be seen in the adoption by the media, and particularly newscasters, of geological terms to denote major structural changes (Figure 3).

'Fault lines dividing the Catholic Church'
ITV News 3.3.96

'Seismic and permanent shift in the gravity of Europe' (re Beef Crisis)
News 10/6/96

'A seismic event'
The critics verdict on the first night of the re-launch of the musical 'Showboat', Front Row BBC 4/98

'Britain and Europe are moving apart, but we couldn't think of a game based on plate tectonics, so we'll have to do something else'
Humphrey Littleton 'I'm Sorry I haven't a clue' BBC Radio 4-4/5/98

'That nice little ammonite cloud is the remains of hurricane Danielle'
Weather forecast 3/9/98

'Rabin's assassination was a tectonic event in Israel's history'
News commentator Channel 4 10/5/98

'Its hardly a seismic shift in Middle England'
Alistair Campbell's comments on Tony Blair's speech to the W.I. Press Conference early July 2000

Figure 3. Geo media quotes.

Although I can only once recall hearing the word 'tsunami' used by a news presenter instead of 'tidal wave', by contrast terms related to plate tectonics are particularly instructive. I read geology at Swansea from 1964, graduating in 1968. In my first year 'continental drift' was mentioned, still considered by some to be rather fanciful, after all it had first been proposed by Wegner, a meteorologist. A whole cluster of different research lines converged in the 1960s so that before I graduated, plate tectonics was firmly in place, although still not mentioned by then in standard texts or dictionaries. By 1992 one of our NSC guides, an engineer, rather patronisingly asked a young 8 year old whether he liked fossils; the visitor's response was that he thought plate tectonics was more interesting!

At the NSC, we confront school groups with the palaeo evidence of tropical seas, a fossil shark's tooth, crinoids and corals; they are then challenged to reconstruct the scene. When asked how can one explain this evidence at a site 230m above sea level and 50km inland, probably 10-20% of a class of average junior school children will volunteer to explain plate tectonics and their attempts will be reasonably accurate. Yet again the subject area is not covered formally in the National Curriculum until pupils are approaching GCSEs. Perhaps more significantly, 'Earth and Beyond' in science throughout the four Key Stages comprises virtually entirely astronomy.

However, all is not lost; even at primary level, as at least there are excellent opportunities to cover rocks and minerals, their properties and uses and later, their processing, chemical changes and the environmental implications of their exploitation. I am happy to say that plate movement, the fossil record/evolution, the formation of rocks and of energy resources and their uses, weathering etc. are all embodied in the revised National Curriculum. Contrast this with your own school experiences. Do not believe the moaners and groaners who complain that 'there is now no earth science in the curriculum'; there certainly is, the problem is that it is often not being taught by those who know much about it and often under duress. Neither does it come with a large earth science/geology label; if it did, the objections would probably be even more vehement.

To those who contend that geology, its scale and scope, is difficult to comprehend, consider the fact that several times each evening, television screens confront us with a confusing, even bizarre array of graphic portrayals of meteorology. We accept this in the light of our national obsession with weather, yet how many non-geologists are aware of even the basics of geological maps?

Gaining experience through fieldwork is also specified in the sci-

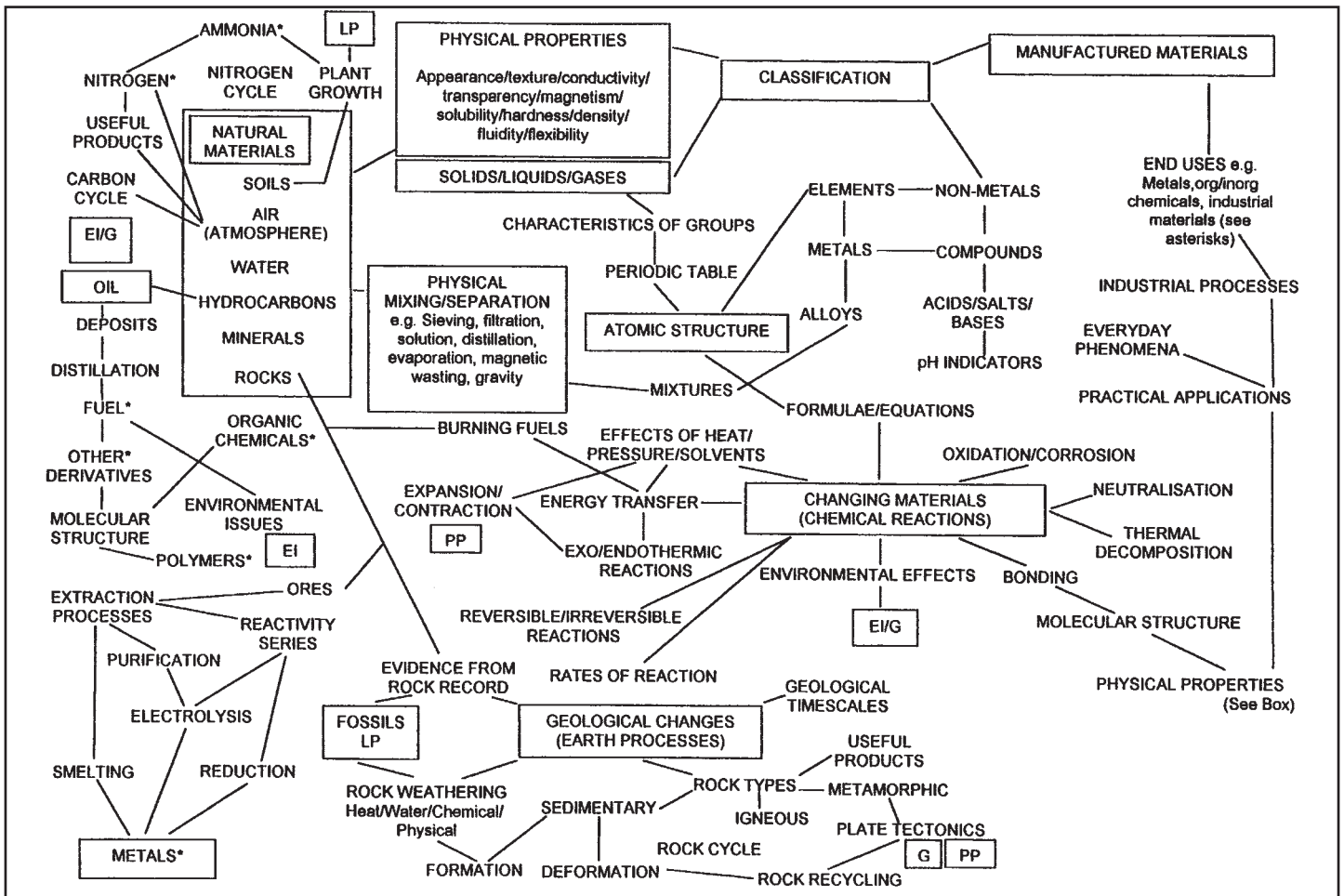

Figure 4. National curriculum links materials/properties mineral extraction/processing. Science web. *end uses. © NSC

ence curriculum, which is more than can be said for a number of university undergraduate courses. We even had one graduate placement with us who had never been in an operational quarry!

Although the number of A level students studying geology per se has declined from nearly 2,600 to 1,800 over the last decade, the quantity of students almost inadvertently learning about earth science as a component of science (a core subject) is unprecedented.

The magic number is **0.033%**

i.e. 4,000 Geology A level/GCSE students

~~12,000,000 National curriculum – scien~~ce students

Far from saying that we should abandon those in schools studying geology as a single subject, we need to wake up to the fact that we have 12 million actual, not just potential, earth science students; it is these we should be targeting more assiduously. But we have to be realistic about what can be achieved with minimal resources. We need to subvert/convert the chemists, physicists and biologists to deliver good quality earth science and, without diluting the scientific integrity, enable them to feel comfortable with the subject (see for example Figure 4). (Hawley 1998). We need to ensure that earth science teachers can also work in some of these disciplines, indeed most of them do so already. ESTA is already exploring this approach and the first indications are very encouraging. There is another positive note: an influential group of science educators are emerging who have recognised that the mismatch of science as now taught in most schools and as specified in the curriculum, contrasts adversely with science as experienced in everyday life and as reported in topical events. They are pressing for a more all embracing approach, still delivering good science. Maybe their views are too radical to be adopted in the next round of policy changes but, if they are accepted, the potential could be enormous. Their approach is to highlight macro themes or 'major ideas' with transport, the built environment, health, information technology, etc., integrating the traditional subject disciplines. (Osborne 1998, Millar & Osborne 1998).

In this cross disciplinary context, it is pleasing to see the results of, for example, one of the most appealing recent educational projects produced by the Royal Society of Chemistry and the National Gallery on Chemistry and Art (Anon 1999).

Why should we do anything? Indeed, can we do anything against such overwhelming odds? One can be reasonably confident in asserting that the vast majority of OUGS student members will not become involved in a career where geology is the key subject requirement. This is certainly not to belittle the profession or an OU degree as the study of geology is highly rewarding in its own right, it is a statement of practical fact. After all in 1997, of about 1,300 first degree earth science students who graduated from 35 institutions, only 21% moved into geologically related employment. Even if one finds oneself working in a directly related subject area, this may well mean operating in an environment dominated by other disciplines (for 17 years, I was a lone geologist as a minerals planner, surrounded by 50 planners) (Ward 1999, Petford 1999).

To take stock, we have an exceptionally small geological community with no obvious Bellamys, Attenboroughs, Patrick Moores or Tony Robinsons to champion our cause; we are faced with considerable 'competition' from other disciplines, wildlife, astronomy and archaeology in the public realm, and in schools chemistry, physics and biology. Yet as we have also seen, we have a reasonably receptive but relatively uninformed national population and a massive school population being taught earth science, albeit in many instances indifferently. There is no doubt that we have missed opportunities – how many in the geological community have lobbied for the safeguarding of earth science interests in the new Countryside Access Bill? or DETR Planning Policy Guidance relating to Nature Conservation or on the Mineral Working Policy draft for Wales, the inclusion of geology as a beneficiary in the proposed Aggregates Levy (Tax) Sustainability Fund, or the major review by English Heritage on building conservation/settings. Amazingly, there was virtually no mention of geology in any of these important consultative documents.

With so small a working base, the only way forward to increase public understanding must be co-operation with others; networking and an holistic approach are the keys.

Returning again to the all-embracing nature of geology, a subject which can bind together a scatter of otherwise disparate themes, let us examine some of the potential links. The concept of 'local distinctiveness' was first developed by the organisation Common Ground in an effort to generate a sense of cohesion in communities, they draw few demarcations between subject areas. Applying this approach to land use as a whole, the NSC has evolved a relationships diagram (figure 5). This again demonstrates the potential centrality of geology.

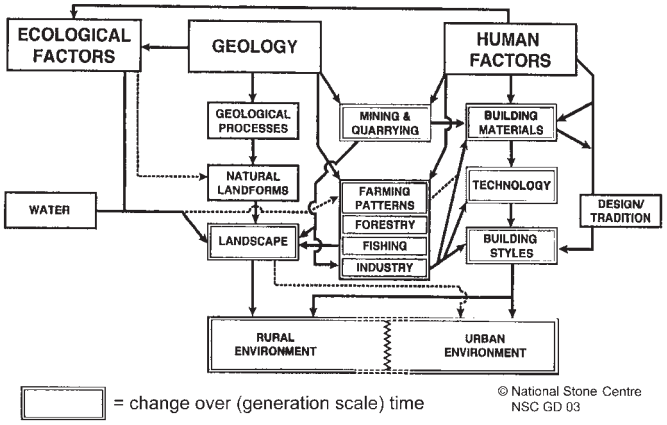

Figure 5. Factors influencing local distinctiveness (term "coined" by Common Ground).

At this point it is worth mentioning two further parallel themes currently in vogue, namely 'Sense of Place' and 'Pride of Place'.

From these we can tease out many opportunities for community involvement, thereby raising the profile of geology at local level:

- •Building Stone/Town Trails
- •Guides to individual 'buildings', notably Cathedrals / Castles / Historic Quarries / Mining Trails
- •Museums and visitor centres
- •RIGS initiatives
- •Input to environment-based courses
- •Parish Paths projects
- •Village Millennium maps
- •Sense of Place survey
- •Collaboration with schools
- •Graveyard Studies

Geology should be integrated as a key component in all of these. Any one of these approaches could be extended into a paper or book, indeed a life's work; many have been recorded, collated or analysed in directories or theses.

Some of these themes are now explored briefly by reference to activities and approaches employed at the NSC. About a third of NSC's income comes from visitors, a third from collecting/disseminating mineral planning data and a third from what can broadly be classed as interpretive work or training (Thomas 1997). Many of these activities come under the umbrella of geotourism, a field in which Britain, or more particularly England and Wales (with one or two recent exceptions such as Cornwall and Dorset), lags way behind the USA, France, Scandinavia and Ireland, at least in a formal sense. There are, however, signs of a shift of emphasis as exemplified in the cases put to the highly successful conference on tourism in geological landscapes in Belfast in 1998.

More work is needed to educate regional and local tourism leaders as to the potential of geotourism as an important strand of sustainable tourism. At the same time we must offer horses for courses; we have to pitch our message at the most appropriate language level, supported by high quality designs. Despite the enlightened rather precocious 8 year old referred to earlier, we need to remember that the average reading age in the UK is that of an 11 or 12 year old. This may surprise some, but even in technical areas outside our own fields when in leisure mode, we tend to downgrade. An example of selectivity is given in Figure 6 prepared by M.F. Stanley for a study of the Derwent Valley in 1979 (Binks *et al.* 1979). Although some of the terms have been superseded, the message is clear.

The problems posed by delivery to different audiences can also be tackled by applying the 'Rupert Bear' principle to interpretation. Rupert Bear was a popular children's cartoon character; the publisher used a series of simple illustrations each supported by a short caption in rhyme and, at the foot of the page, a longer text of the story. The process can thus be absorbed at any one of three levels or combinations thereof. In our case, the picture may again be an illustration, diagram, artifact or specimen, amplified below by a brief caption, itself extended by a more technical explanation for the keen 'long stay' reader. (Anon 1997).

Needless to say, we shall still be confronted by dilemmas, for example, in devising building stone trails do we apply geological terminology rigidly? In which case we would not refer to traditional trade terms such as Ashburton or Hopton Wood **Marble** or Stone/Grey **Slates** (i.e. fissile sandstones), the existing common words marble and slate were captured by geologists in the nineteenth century and in the process, their use became restricted to metamorphic rocks. To maintain this geological stance removes confusion, for example when talking to school groups, but rather arrogantly overrides traditions which long predated the tighter usage. A more legitimate stance would be to explain that two lan-

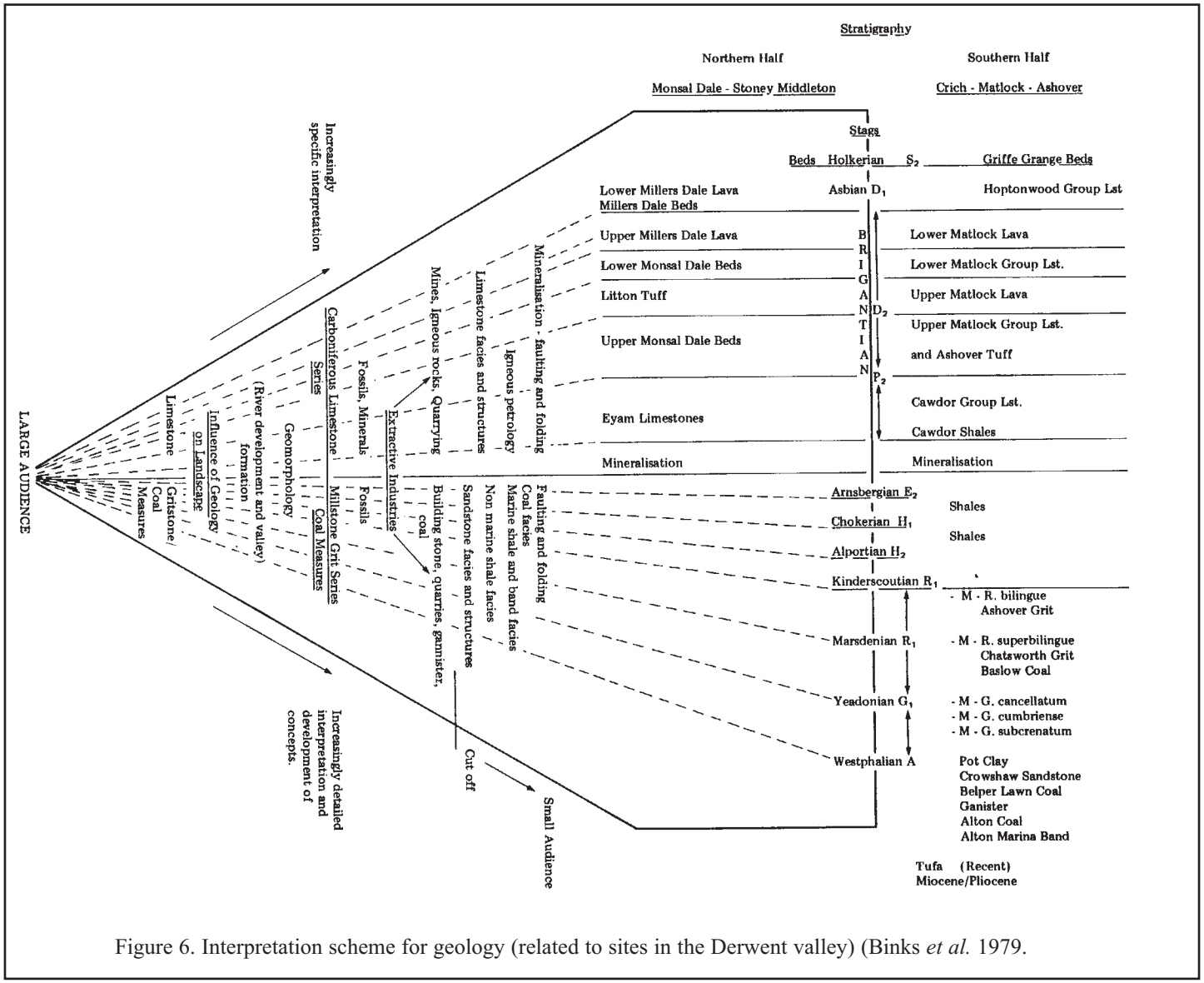

Figure 6. Interpretation scheme for geology (related to sites in the Derwent valley) (Binks *et al.* 1979.

guages exist in parallel, without losing scientific integrity.

Who will undertake these tasks?

Open University earth science students are particularly well placed. Courses are well informed with a strong topical and applied bias. OU students are also more widely dispersed throughout the UK (and beyond) and usually have closer community affinities than those of conventional universities, yet have an established network and central reference point at Milton Keynes. Almost all OUGS members operate in non-geological settings but, by their very nature, may well have work or leisure links with organisations capable of gaining from geological input, whether as school governors, members of local wildlife trusts/geological societies or through work in the extractive or media sectors. Others may find themselves a single earth scientist surrounded by a sea of architects, engineers or planners. Recognising that the time of most OU students is taxed by family, work and study commitments to a higher degree than most of the population, this is an added challenge and it may be much more appropriate to consider such involvement as a valuable and stimulating means of pursuing an interest in earth science after graduating. It is up to all of us to raise the profile of earth science by becoming a volunteer, a lead science teacher in a primary school, or influencing your local community or quarry company to provide trails or viewpoints with a geological context. We have even used the current instant gardening craze as a means of increasing awareness of geology.

The only way in which the NSC has been able to progress such initiatives is via a multiplicity of partnerships (Figure 7). Our total staff of four full timers is miniscule, plus of course a willing band of able volunteers, many of whom are OU students, yet another partnership, and at this point I would like to pay very special tribute to them.

As an indication of the potential for communicating geological information to others, one only has to look at the list of over 400 organisations for which the British Geological Survey carried out work or collaborated with in a single year. Voluntary linkages of the types already referred to could be increased at least a hundred fold.

Finally one may well ask, how are some of the hard costs to be funded for print, travel, paths, interpretive panels, design work? Happily, after many years in which funding had become ever more problematic, new sources such as the Local Heritage Initiative and the New Opportunities Fund, and, in future, the proposed Aggregates Levy Tax Sustainability Fund, can be tapped. The, by now well established, Landfill Tax Credit Scheme has

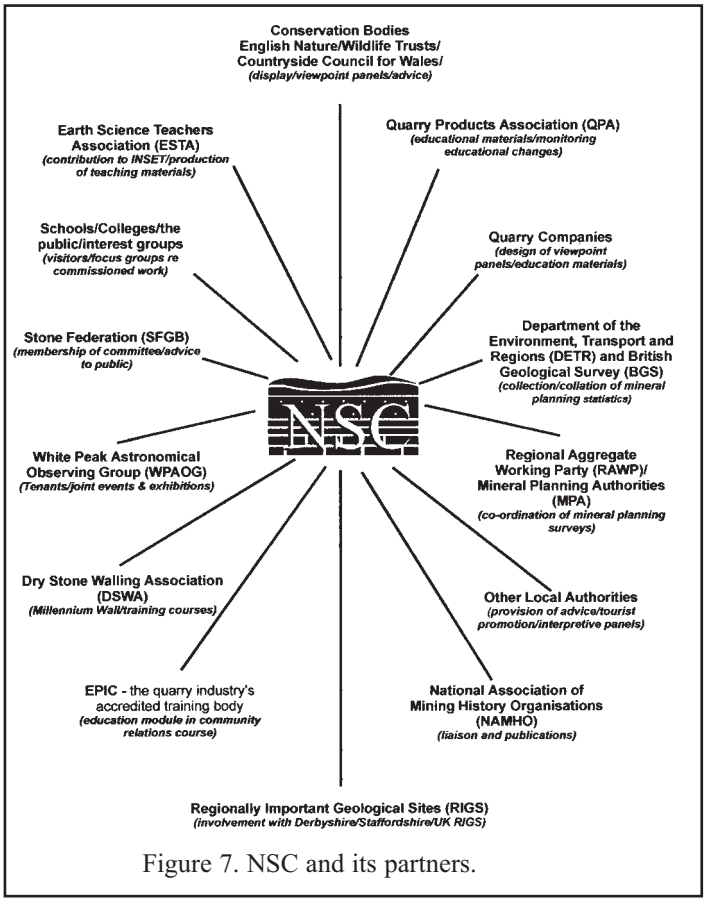
Conservation Bodies
English Nature/Wildlife Trusts/
Countryside Council for Wales/
(display/viewpoint panels/advice)
Earth Science Teachers Association (ESTA)
(contribution to INSET/production of teaching materials)
Quarry Products Association (QPA)
(educational materials/monitoring educational changes)
Schools/Colleges/the public/interest groups
(visitors/focus groups re commissioned work)
Quarry Companies
(design of viewpoint panels/education materials)
Stone Federation (SFGB)
(membership of committee/advice to public)
Department of the Environment, Transport and Regions (DETR) and British Geological Survey (BGS)
(collection/coliation of mineral planning statistics)
NSC
White Peak Astronomical Observing Group (WPAOG)
(Tenants/joint events & exhibitions)
Regional Aggregate Working Party (RAWP)/ Mineral Planning Authorities (MPA)
(co-ordination of mineral planning surveys)
Dry Stone Walling Association (DSWA)
(Millennium Wall/training courses)
Other Local Authorities
(provision of advice/tourist promotion/interpretive panels)
EPIC - the quarry industry's accredited training body
(education module in community relations course)
National Association of Mining History Organisations (NAMHO)
(liaison and publications)
Regionally Important Geological Sites (RIGS)
(involvement with Derbyshire/Staffordshire/UK RIGS)

Figure 7. NSC and its partners.

been helpful to some, although the bulk appears to have been employed in wildlife projects and local authority schemes. Despite the obvious links with geology, many good related schemes have lost out.

The Curry Fund of the Geologists' Association also provides support to modest proposals. English Nature and the Countryside Agency are able to assist although the eligibility rules for schemes do change quite frequently. The Heritage Lottery Fund still provides grants for larger schemes although many will be astounded to learn that the Millennium Wall project by the Dry Stone Walling Association at the NSC (19 full scale examples of walls from all over Britain) was unsuccessful "as the features were not permanent and lacked community involvement"!! Lottery funds are indeed a lottery, as are many Eurofunds.

The message must be to go out and spread the word. Despite the apparent odds we have probably 'never had it so good' in terms of an interested public, an increasingly informed school population and even potential funding.

Appendix 1

Selective CV

References and Notes

A level subjects: Art (Option Gothic Architeture Geology Geography Chemistry (failed)	Undergraduate subject: Yr 1 Geology Geography Physics Yr 2 Geology Geography Biology Cartography Yr 3/4 Geology

First post	Economic Geologist
Second post	Minerals Planner
Third post	Manager including the above
Freelance work	Design Graphic design/artwork

Anon, 1997, *Rupert Bear. Daily Express Annual*, Pedigree Books.

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Ward B, 1999, Graduate geology scientists Survey 1997. *Geoscientist* **9.4,** 4-10.

Acknowlegement

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Book review

Stepping Stones: The making of our home world by Stephen Drury, 1999, Oxford University Press, 409pp, £19.99 (hardback), ISBN 0198502710.

This book, by one of our OU Earth Sciences Lecturers, covers much the same ground as S269 – Earth and Life. The style is quite different though; it's written like many of the other popularising science books which are becoming more and more available. The approach is opinionated and quirky, and made me laugh out loud on several occasions. Steve Drury has a dry sense of humour which sneaks up on the reader. I shall never again eat pickled onions whilst drinking beer ...! But, as well as the humour, the explanations are very clear; there is a very good description of the formation of banded ironstones, for example.

It's not a book to read in one go, there's too much in it for that; and it's not a text book, but one or two S269 students have found it and liked it as an enjoyable extra. Others had found the new third level book *The Great Ice Age* by Chris Wilson *et al.* more to their taste, but then that is a textbook! Stepping Stones is worth a look for an interesting take on the subject.

Jenny Bennett, BA Hons (Open), OU Tutor

Can we still see the wood for the trees? Synthesis is more challenging than ever - - or - - A Plea for Plate Tectonics

Lorcan Kennan, Tectonic Analysis Ltd

Introduction

Thirty years ago, the newborn Plate Tectonics paradigm provided a framework for interpreting geological data and changed forever the way we look at earth history. Although successful in the marine arena, many interpretations of continental regions have been discredited as "arm-waving" because of poor data quality or because simplistic rigid-plate models cannot be easily applied to complex continental plate boundary zones. Now, we possess enormous quantities of much higher quality data and our understanding of processes affecting the continental crust is much better. However, this improvement parallels a decline in the appreciation by many geologists of the "rules" of Plate Tectonics which still apply, albeit with modifications.

In this paper I will show how a very large scale overview can provide key insights into the geology of much smaller regions. The essence of the problem is this: we can never work backwards from the data we have, no matter how good it is, to a unique solution to a geological problem. There are simply too many alternatives. Instead, we must narrow the field by working forward from well-defined starting points which may come from looking at very different regions. Northern South America and Mexico are areas where the "inversion problem" gives us too many options if we look at local geology alone, and the literature is peppered with elegant, internally consistent but incompatible models. How do we pick between them? It turns out that we can and the geology of Northern South America and West Africa provides an excellent constraint on how central America and the Caribbean evolved since the Jurassic, even though relatively little undisturbed geology of that age is preserved in the region.

Closing the Equatorial Atlantic: Reconstructing the South America - Africa Supercontinent

The first stage in our forward model is to consider the Atlantic Ocean. The age of the ocean floor is well-defined and it is clear that the Equatorial (west of Nigeria) and Southern (south of Nigeria) Atlantic did not exist prior to about 120Ma and only a narrow Central Atlantic (Guinea to Spain) was open. Simple fits of the shapes of the two continents are well-known but generally do not satisfy geological data in the Equatorial region. Why is this? The continental outlines used in these reconstructions are not entirely appropriate because they are based on present day maps. We have to take into account the major rifts that affected the interior of both continents just before and during rifting and early ocean formation (for instance, through Nigeria, Camaroon and Chad in Africa and in the Amazon region of South America) which changed the shapes of both continents. We must also take into account the thick post-rift sedimentary sections at the edges of Africa and South America to accurately restore the pre-rift shapes of continental blocks and margins.

Continental rifting reflects divergence of relatively stable portions of crust. This is accommodated by crustal extension at shallow levels (typically < 15km) by normal faulting and at depth by ductile stretching of the lower crust and upper mantle. The end result is lithospheric thinning at the rift; we usually see overall tectonic subsidence of the surface, elevation of the asthenosphere, increased heat flow and, sometimes, volcanism. At the surface, fault bounded grabens first fill with red beds as rifting proceeds. These are then overlapped by "thermal sag" sedimentary sections driven largely by cooling of the asthenosphere plus the loading effect of the sediments themselves. Where extension is sufficiently large, oceanic crust is created and the two portions of continental crust drift apart. At the rifted margins which flank ocean basins, sediment thickness can exceed 16km. If sediment supply is sufficient, for instance near deltas or adjacent to high-relief topography in wet climates, the position of passive margin features such as the shelf-slope break (used for Bullard's famous 1965 reconstruction) can change significantly with time, growing out from the coast and well beyond the original limits of the continental crust.

To gain a much closer approximation of the shapes of rifted margins to fit together for a more precise pre-rift geometry, we must construct cross sections of rifted margins which depict the thicknesses of the water column, the sedimentary section and the crust. Water depth and total sedimentary section are often known from geophysical studies at passive margins. The position of the Moho (base of the crust) can be crudely estimated by the balancing of water, sediment, crust and mantle using Airy isostatic calculations and, where gravity data or detailed sedimentological data are available, refined by taking into account crustal flexure and sediment compaction. Once the cross-sectional shape of the rifted margin's crust is inferred, the syn-rift extension in basement can be removed by restoring the cross-sectional area of the rifted margin shoulder back to an unstretched beam of continental crust (typically crust that started 30km thick can be stretched to only 5-15km thick). Thus, we can identify the original pre-stretch limits of the continent and use this shape to close opposing continental margins against each other.

Figure 1 shows the result of this method applied to the rifted margins of the Equatorial Atlantic. The correction is particularly important along the shelves at the mouths of the Niger and Amazon rivers, where the sedimentary thickness exceeds 10km over large areas. A satisfactory fit can be achieved to an accuracy of perhaps 50km. For comparison, the inset of Figure 1 shows the classic Bullard reconstruction of the two continents, with the pre-rift shapes of basement shown rather than the 2,000m isobath employed by Bullard. The inferred underfit in the Bullard reconstruction approaches 500km. Because continental reassembly in the Gulf of Mexico region is achieved by rotating the Africa-South America "super-continent" reconstruction back towards North America using Central Atlantic kinematic data, the difference between the two approaches will profoundly affect the final reassembly.

Closing the Central Atlantic: The Jurassic reconstruction for the Gulf of Mexico and Caribbean

Figure 2 shows a series of reconstructions of our united Africa-

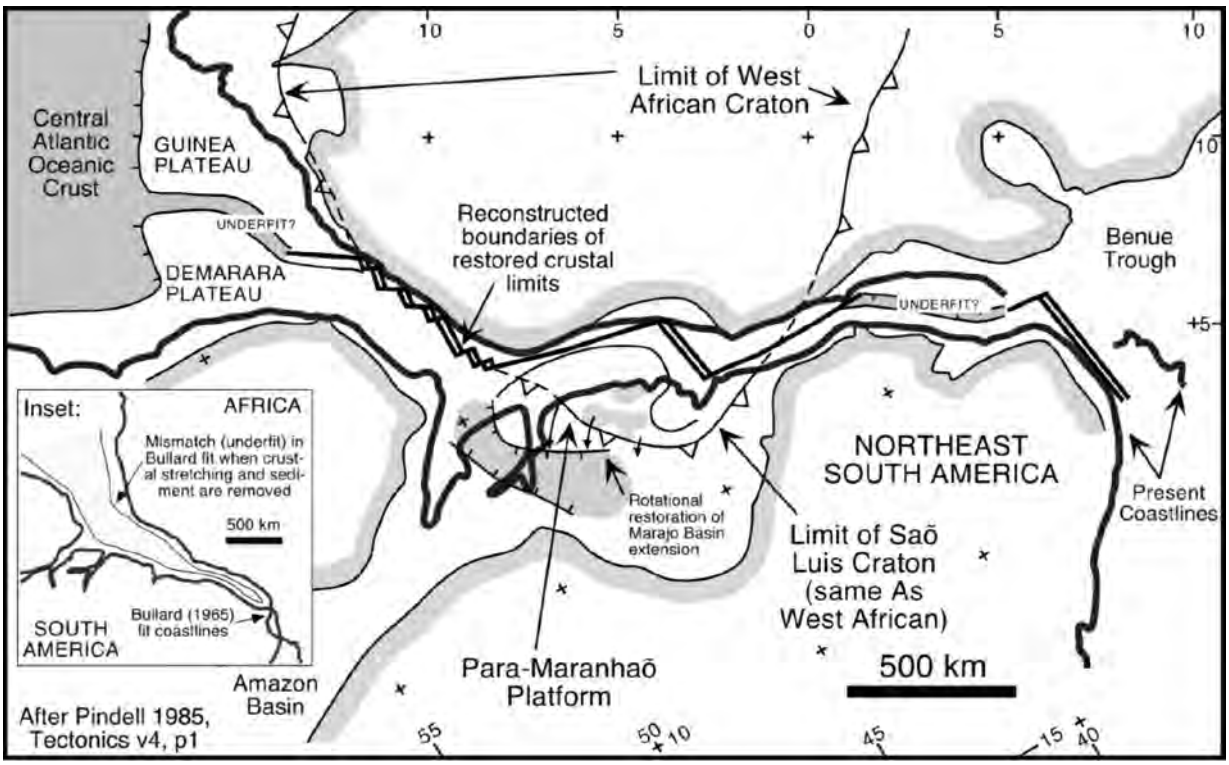

Figure 1. Pre-Aptian Equatorial Atlantic reconstruction in which the restored pre-rift limits of continental crust of West Africa and Brazil are juxtaposed. Note resulting simple geometry for Aptian rifting. Inset: Bullard's (1965) reconstruction of the two continents, which realigned the 2,000m isobaths of today's passive margins (not shown), showing the pre-rift limits of continental crust for each, as well as the large region of continental underfit in which there is no evidence for Jurassic sedimentary sections.

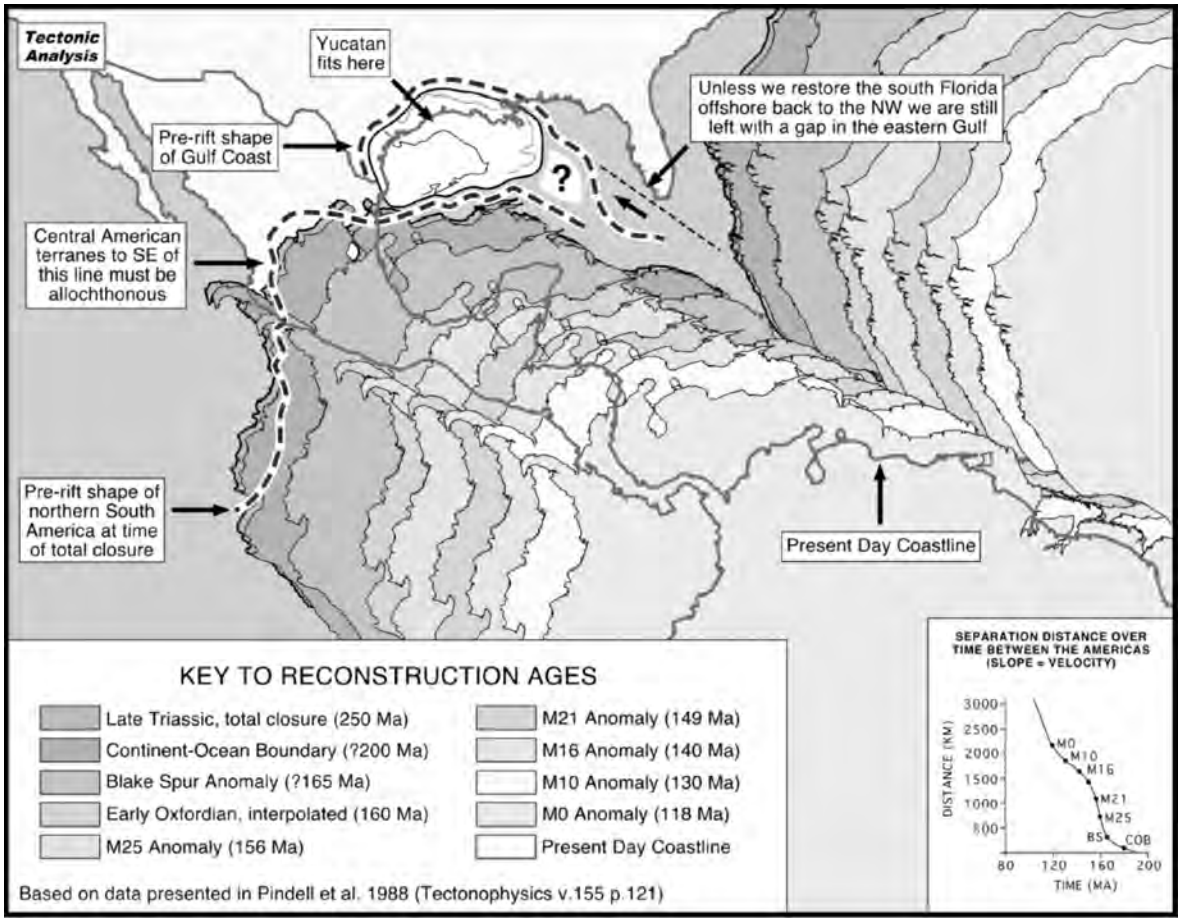
Tectonic Analysis
Yucatan fits here
Unless we restore the south Florida offshore back to the NW we are still left with a gap in the eastern Gulf
Pre-rift shape of Gulf Coast
Central American terranes to SE of this line must be allochthonous
Pre-rift shape of northern South America at time of total closure
Present Day Coastline
KEY TO RECONSTRUCTION AGES
Late Triassic, total closure (250 Ma)
Continent-Ocean Boundary (?200 Ma)
Blake Spur Anomaly (?165 Ma)
Early Oxfordian, interpolated (160 Ma)
M25 Anomaly (156 Ma)
M21 Anomaly (149 Ma)
M16 Anomaly (140 Ma)
M10 Anomaly (130 Ma)
M0 Anomaly (118 Ma)
Present Day Coastline
Based on data presented in Pindell et al. 1988 (Tectonophysics v.155 p.121)
SEPARATION DISTANCE OVER TIME BETWEEN THE AMERICAS (SLOPE = VELOCITY)
DISTANCE (KM)
TIME (MA)
M0
M10
M16
M21
M25
BS
COB

Figure 2. Successive pre-Aptian reconstructions of Gondwana and North America, using the Equatorial Atlantic fit of Figure 1. This analysis provides a quantitative framework in which to build more locally detailed models of the evolution of the Gulf of Mexico and surrounding areas. Note pre-Andean/pre-rift restoration of the northern Andes on the Triassic position of South America: this defines how much of Mexico is definitely allochthonous versus how much is potentially, but not necessarily, autochthonous.

South America supercontinent and North America for Aptian and older times, prior to Equatorial Atlantic break up. The positions were calculated by using data on ocean crust ages in the Central Atlantic. For any particular age, we simply remove the younger ocean crust from an ocean crust age map and match the edges in west and east. For simplicity we have kept North America locked in position. In reality, all the continents were moving with respect to a magnetic reference frame (for example, North America has rotated 20° or more anticlockwise). The analysis tells us how fast and in what direction the North America and South America/Africa separated between ca. 250Ma and 120Ma. This in turn constrains the possible geometries of oceanic ridge systems between the Americas, and also the size and shape of the inter-American gap through time, which we refer to as the "Proto-Caribbean". Figure 2 also shows the pre-rift shape of the northern Andes region superimposed on South America for the Late Triassic time slice. This was drawn by taking away any terranes accreted to the edge of South America during the Cretaceous-Cenozoic building of the Andes (including fragments of ocean crust sliced off the subducting Pacific plates and pieces of continental crust faulted in from farther south in Ecuador). We also undid the effects of massive Andean shortening (up to 200km in a roughly east-west direction) and restored the stretching required to explain deep Jurassic and Cretaceous basins in Colombia.

The relationship of North and South America at this time is important because it defines a line separating two parts of Mexico. The part of Mexico overlapped during Late Triassic time by South America must have migrated into today's position as a function of Gulf of Mexico evolution, Cordilleran terrane migration, and/or Sierra Madre/Chiapas shortening history. Parts of Mexico not overlapped by South America during the Triassic may have been in place relative to today's geography, but were not necessarily so. From Figure 2, the fact that the formation of the Gulf of Mexico was completed by early Cretaceous time implies that Jurassic plate boundary systems active in the Gulf until then probably also controlled many primary elements of the evolution of Mexico. Thus, the stage is set for us to use the constraints developed here to reconstruct western Pangaea and to trace the Mesozoic plate-tectonic evolution of the Gulf of Mexico, eastern Mexico, the Florida/Bahamas region and the Proto-Caribbean Seaway.

Forward modelling from Jurassic to Cretaceous time:

Having defined a kinematic framework for the evolution of the Gulf of Mexico region by restoring Andean deformations and progressively closing the Atlantic Ocean, we further evolve this framework to build a palinspastically quantitative reassembly of continents and continental blocks that were separated during the Mesozoic rifting and subsequent drift in the Gulf of Mexico region. Figures 3 to 6 show our proposed evolutionary sequence from Early Jurassic to Middle Cretaceous time.

One of the most striking features of the model is that the Yucatán Block moved independently of the larger continents as the Gulf opened. The original position of this block has been the subject of a great deal of controversy, with some models wanting it to lie where north-central Mexico is today. However, Figure 2 suggests that there is only a small range of palaeo-positions in which Yucatán could have fit geometrically, snugly up against the north-east Mexico-Texas-northwest Florida palaeo-margin. However, it does not close the southeastern Gulf. There, the crust offshore South Florida must be retracted northwestward against Yucatán, and out of an overlap position with Demerara Rise, off the Guyana margin.

A well-defined ESE fabric of related transform faults is apparent on all our maps between Florida and Guyana.

The geology of the eastern Mexican margin and the occurrence of Louann and Campeche salt suggest that the Gulf of Mexico opened in two stages. The first, or syn-rift, stage – between the times of Figures 3 and 4 – involved intra-continental stretching between Yucatán and North America with rotation about a pole off the eastern US and between Yucatán and South America about a pole off southern Mexico (present day coastline is shown on the maps). This migration defined an arcuate transcurrent trend defined by basement contours along the northern Tamaulipas Arch in south Texas and also created the wedge-shaped East Mississippi and Apalachicola salt basins to the north of the Gulf. At the end of this "syn-rift" phase, there was an enormous Middle Jurassic (pre-Oxfordian) salt-filled basin in the Gulf of Mexico, the torn edges of which are now present off the US Gulf coast and the north coast of Yucatán, Mexico. Also, during this stage, the southern Bahamas crustal corridor migrated SE in addition to undergoing internal stretching – hence, the Everglades fracture zone and the Guyana marginal fault zone were both active at this time.

The second stage of Yucatán motion began in the Early Oxfordian, at the end of salt deposition, and involved rotation of Yucatán with respect to North America about a pole located off southwestern Florida. This stage of motion and its pole of rotation are constrained by geophysical data along the eastern Mexican margin, which show an abrupt NNW-SSE trending ocean-continent boundary (a transform fault); by magnetic anomaly data in the eastern Gulf (which define the boundary between oceanic and continental crust); and by matching up of the once-adjacent margins of the Louann (US) and Campeche (Mexico) salt basins. Figures 4 and 5 bracket this second phase of Gulf of Mexico opening.

Together with the Gulf of Mexico, the synchronous creation of the "Proto-Caribbean Basin" also must have involved a rotational opening between Yucatán and Venezuela-Trinidad. Figures 3 to 5 show the approximate way in which this basin opened, as well as a hypothetical geometry of its Jurassic rifted margins – now wholly overthrust by allochthonous Caribbean terranes which came in from the Pacific region.

The final significant development in the Proto-Caribbean is bracketed by Figures 5 and 6. At about 130Ma the proto-Caribbean Seaway had opened wide enough for Yucatán to have reached its present position. Stretching in the Gulf of Mexico stopped and simple thermal subsidence took over as the underlying stretched lithosphere began to cool down. Because rotation between Yucatán and South America had also stopped there was a slight reorganisation in the oceanic ridges in the Proto-Caribbean. Figure 6 shows our calculated position for the Americas at about 120Ma. Why is this time significant? Out in the Pacific, buoyant oceanic crust collided with the west-facing subduction zone opposite the Proto-Caribbean and the subduction direction flipped, driving the Caribbean Plate eastwards over the

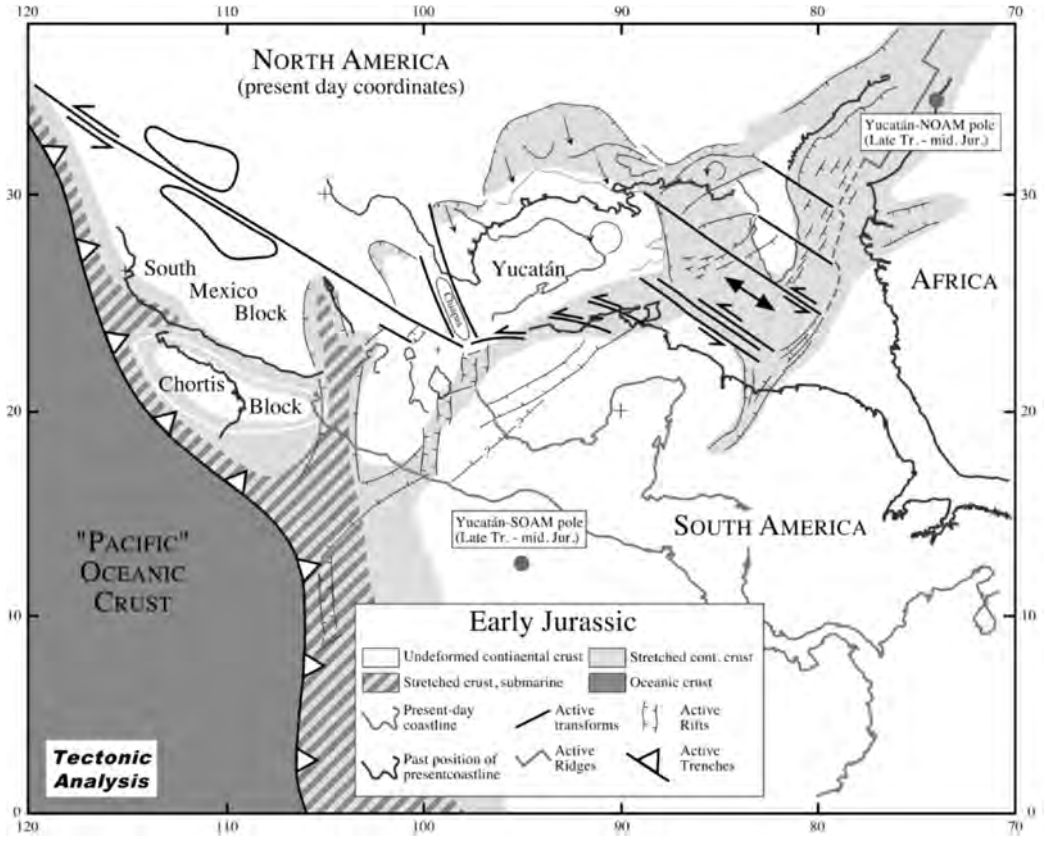

Figure 3. Early Jurassic reconstruction of the Gulf of Mexico and Proto-Caribbean region. Onset of "syn-rift" stage.

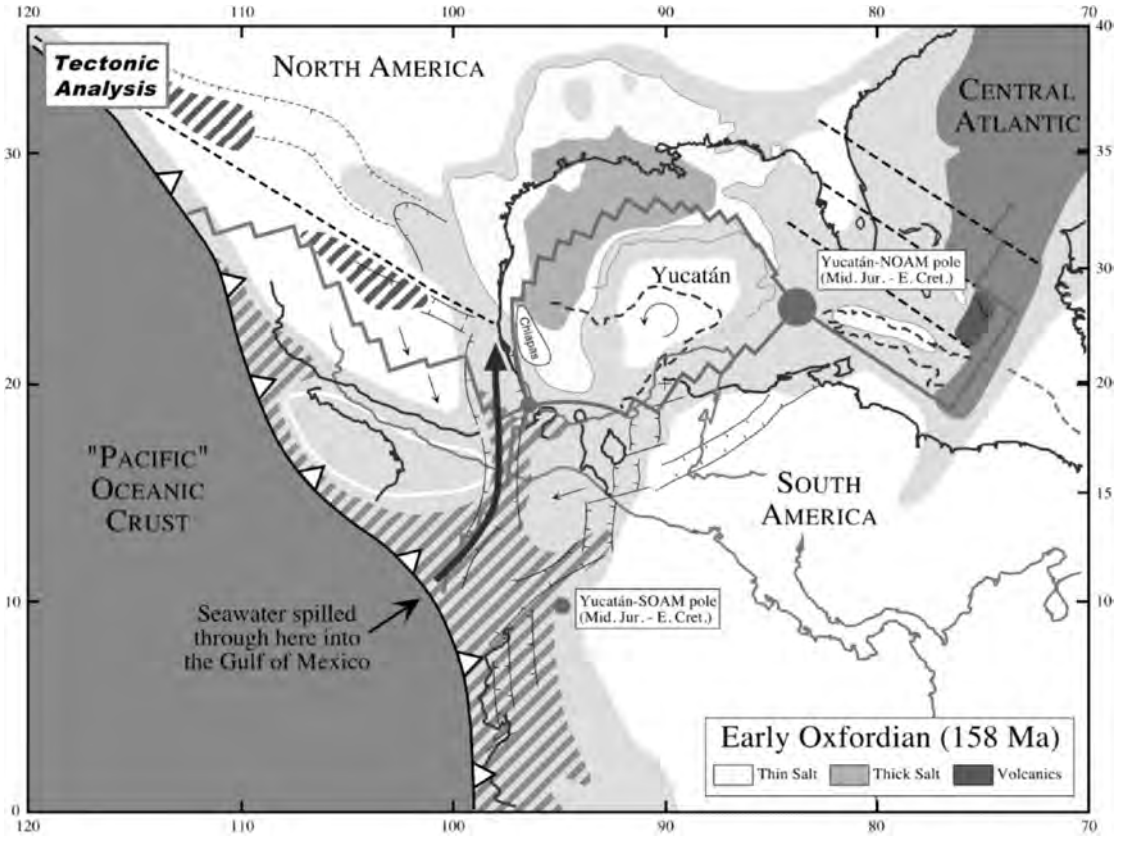

Figure 4. Late Jurassic (Early Oxfordian) reconstruction of the Gulf of Mexico and Proto-Caribbean region ("salt fit"). This time sees the onset of seafloor-spreading. Note that the bulk strain direction in Mexico shifts from ESE-ward to S-ward at this time, with the opening of the Mexican back-arc basin.

Proto-Caribbean and almost entirely destroying the evidence for that older oceanic basin.

What kind of implications are there?

How robust is this modelling? No small number of geologists are suspicious of what they see as more "arm-waving". In part this is because so much really bad arm-waving was done particularly in the early days of Plate Tectonics, when data were few and far between. To be reliable, good modelling must have the following characteristics:

1) Every map we draw must be internally consistent. We must not draw geometrically impossible plate boundaries or palaeogeographies.
2) Every map must be consistent with the map that went before and the map that comes after with a clear logic behind how we evolve the plate boundaries. This is where many tectonic models fail dramatically.
3) Every map must be drawn iteratively. We must back up and think as soon as we find something that is not consistent with a clear piece of geological data (note data, not model - we do not always agree with other people's syntheses).

If our models obey these rules we can make predictions over a much wider area than is possible from looking for years and in great detail at the geology of any one country. For instance, there are many possible ways to look at the geology of Cuba, given what we know about Cuban rocks, but only a small subset of these models will be consistent with the geology and tectonics of Mexico of Venezuela. Thus the modelling allows predictions which are not immediately obvious. For instance:

The Eastern Mexican margin (unlike that of Texas) was a Jurassic fracture zone in the north (Burgos-Tampico basins) and a transform – with active structuring until its Early Cretaceous death – in the south (Veracruz basin). Heat flow, subsidence history, occurrence of salt, distribution/thickness of Late Jurassic source rocks, and basement controls on future structural development will all vary along strike along this margin due to differing crustal properties and histories. In contrast, in the U.S. Gulf margins, early syn-rift stretching was NNW-SSE until Early Oxfordian times, but most of the stretching toward the end of this phase occurred well offshore.

Although salt deposition is generally assumed to be of Callovian age, there is little possibility of open marine conditions in the Gulf margins until upper Oxfordian, and thus salt deposition may have continued until Early Oxfordian. Our Early Oxfordian reconstruction accommodates known salt occurrence in the Gulf ("salt fit"); hence, we consider that onset of seafloor spreading, the change in the Yucatán-North America pole position, separation of Louann and Campeche salt provinces, and initiation of open marine conditions were nearly coeval and possibly causally related.

Although the syn-rift stretching of the Florida Shelf region was NW-SE, the extension direction in the deep eastern Gulf during stage 2 (seafloor spreading) was NE-SW about a nearby pole such that transform faults should be arcuate and convex to the NW. In Cuba, a significant area of Bahamian crust was overthrust by Cuban arc assemblages in the Palaeogene. In the Jurassic, the southern Bahamian margin (beneath Cuba) experienced sinistral strike-slip tectonics along the Guyana margin of South America, followed by the eastward migration of a Late Jurassic seafloor spreading ridge (Yucatán/South America boundary) along the western half of the overthrust zone. The transform nature of this Jurassic margin should be considered in interpretations of the Palaeogene development of the Cuban thrust belt, Mesozoic source rock palaeogeography, and oil migration pathways during Eocene maturation.

In the Proto-Caribbean, the kinematics require westward-propagating Early and Middle Jurassic rifting, followed by Late Jurassic seafloor spreading. The trends of marginal re-entrants such as that defined by the Urica basement transfer zone are defined by the first stage of Yucatán's motion. Venezuela-Trinidad's passive margin section is predicted to have existed from the end of Middle Jurassic, not Cretaceous as is commonly thought. A several kilometre-thick, probable Late Jurassic shelf section in Eastern Venezuela has not received much attention from exploration, and the "Berriasian or older" salt in Gulf of Paria (east Venezuela) could be Middle Jurassic (as is the salt in the Bahamas, Guinea Plateau and Demerara Rise and Tacatú Basin). In Sierra Guaniguanico of western Cuba, the conjugate margin of Eastern Venezuela, the lower Middle Jurassic San Cayetano strata indicate the existence of a juvenile passive margin of that age, becoming fully marine for Late Jurassic, as predicted here for Venezuela and Trinidad.

Conclusions

I hope this paper has convinced you that large scale plate tectonics still has a vital role to play in understanding regional geology. Almost in parallel with better data coming out of the oceans and mountain belts there has been a drop in interest in tectonics (both in industry and academia) just when we finally have the data to really refine it. In industry, teams with one or more members with the kind of long term familiarity with the geology of many neighbouring countries are being broken up in favour of "hit-squads" who may have individual skills but who will not always be as clear on regional geology as they should be. In academia, there has been a steady move away from "traditional" geology in favour of environmental sciences or very technical laboratory-based science. Tectonics research, paralleling trends in sedimentology and igneous geology, has moved away from long-term synthesis and the emphasis is increasingly on getting a better understanding of short-term processes.

However, nothing betters a robust understanding of Plate Tectonics for developing links between the geology of adjacent regions. Even though the processes are a lot more subtle than was thought to be the case in the 60's and 70's, we must still attempt large-scale synthesis if we do not want to waste time reinventing the wheel. The implications for areas such as resource assessment or climate-change cannot be overstated. The challenge is to manage and interpret the data we have and to build and coordinate long-lived multidisciplinary research teams. Inevitably this may involve some rethink of how we fund and evaluate our scientific activities.

Further reading

Bullard E C, Everatt J E & Smith A G, 1965, The fit of the continents around the Atlantic. *Philosophical Transactions of the Royal Society of London*, **258A**, 41-51.

Cox A & Hart P B, 1986, *Plate Tectonics - How it works*, Blackwell Scientific Publications.

http://www.tectonicanalysis.com

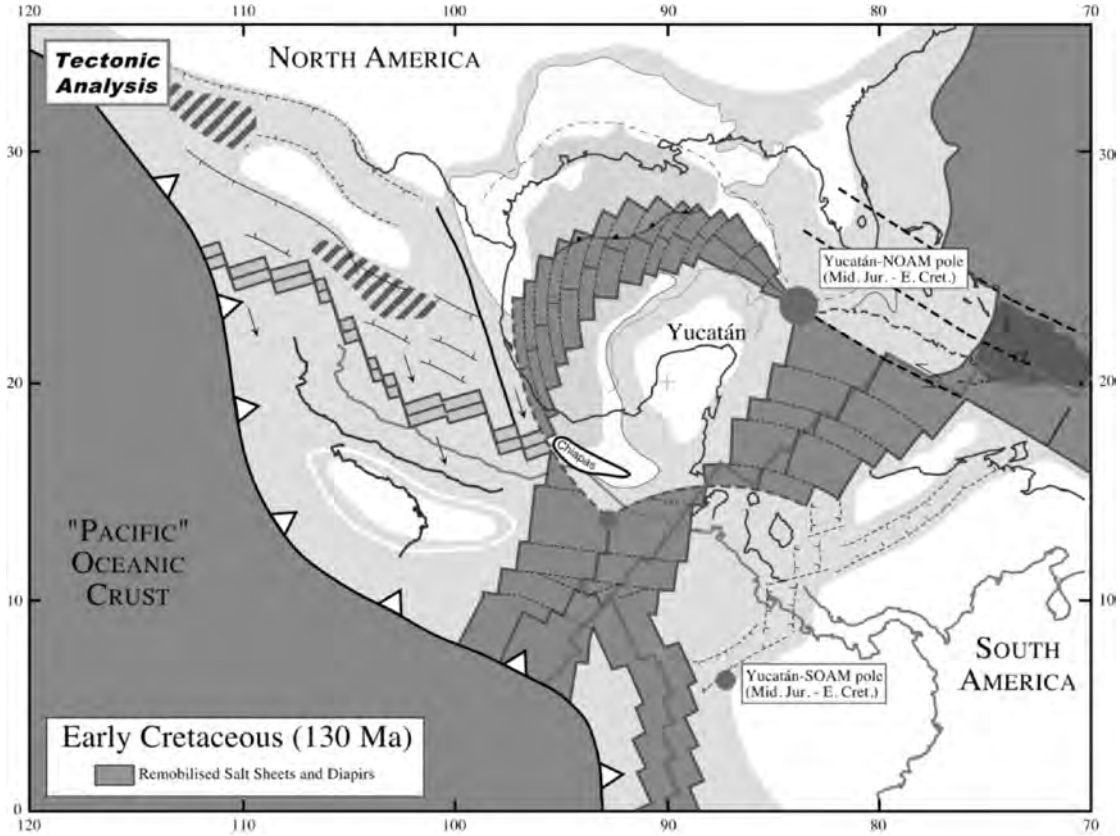

Figure 5. Early Cretaceous (Valanginian) reconstruction of the Gulf of Mexico and Proto-Caribbean region. The Gulf of Mexico has stopped opening - the gap between the Americas is only now wide enough for Yucatán to fit in its present position with respect to Mexico. Seafloor spreading was continuing in the Proto-Caribbean seaway.

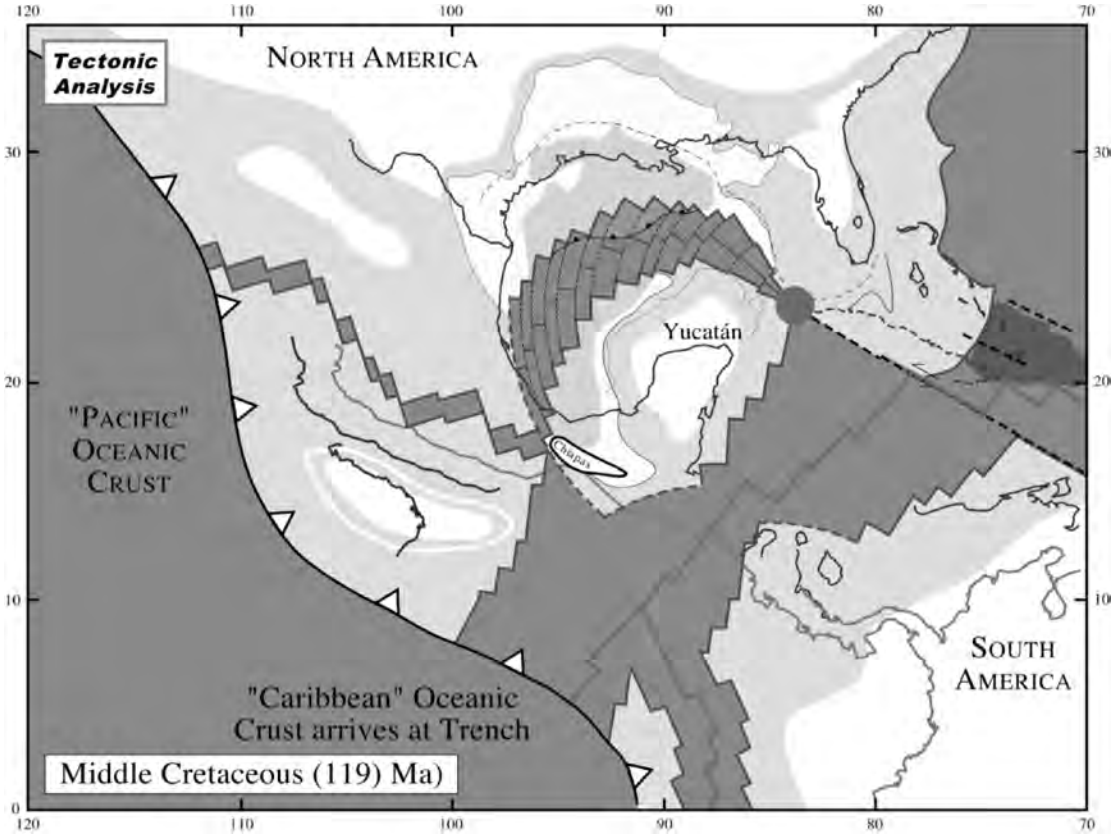

Figure 6. Latest Early Cretaceous (Aptian) reconstruction of the Gulf of Mexico and Proto-Caribbean region. Since the early Cretaceous, seafloor spreading was concentrated on a single oceanic ridge system in the Proto-Caribbean. Out in the Pacific, buoyant oceanic crust (future Caribbean) was approaching the trench and soon collided, choking it and forcing the subduction direction to reverse, allowing the Caribbean Plate to enter the intra-American gap.

The New Eco-museum of the Cornish Industrial Landscape

Stuart B Smith MSc, FMA, Chief Executive, The Trevithick Trust, Cornwall

Having worked for over thirty years in the Museum environment it is interesting how my own career has actually reflected changes in the philosophy of industrial museums. After graduating with Degrees in Human and Physical Sciences in London, together with a Masters Degree in the History of Technology at Manchester, my first job was in Sunderland in the North East of England, where industry was closing down.

I was responsible for rescuing not only the last remains of ship-yards, collieries, rope works and potteries, but also items generated by large scale urban renewal which was affecting the North East at this time. I became involved in rescuing many items, not only for the museum for which I was working in Sunderland, but also for the projected Open Air Museum at Beamish which was going to reflect the entire life of the North East of England. The concept here, however, was to remove everything of interest from the region and to recreate it on a greenfield site without any archaeology. Several of us became unhappy with this concept and I left the Beamish volunteers in order to set up an Organisation to preserve the magnificent water pumping station at Ryhope.

Shortly after this I heard that there was a possibility of establishing an Open Air Museum at Ironbridge in Shropshire (Figures 1&2). I joined the staff of the museum in 1971 as its first Curator, when Neil Cossons, now Sir Neil Cossons of the Science Museum in London, was its first Director. The concept behind lronbridge was to restore all the industrial monuments (Figures 3&4) in a small valley, some 5km by 2km, and to create an open air museum on the Blists Hill site which would recreate a Victorian village of about 1900. This involved costumed demonstrators, use of Victorian monies, the active use of demonstrations, including manufacture of wrought iron (Figure 5) and cast iron, farm animals, and many other novelties for the visitors.

Figure 1. Ironbridge

However, both Beamish and lronbridge were basically inward looking. They were concerned to bring many visitors to the site largely for economic reasons, but they had no real concern to get people to go out and explore the industrial landscape outside the museum confines.

After 20 years at lronbridge, the last eight as Director, I was approached to come to Cornwall to create a rather different sort of environmental museum. Cornwall is the furthest south-west tip

Figure 2. The River Severn at Ironbridge Gorge.

Figure 3. Clay Mine, Blists Hill.

Figure 4. Coalport China Clay Museum, Ironbridge Gorge.

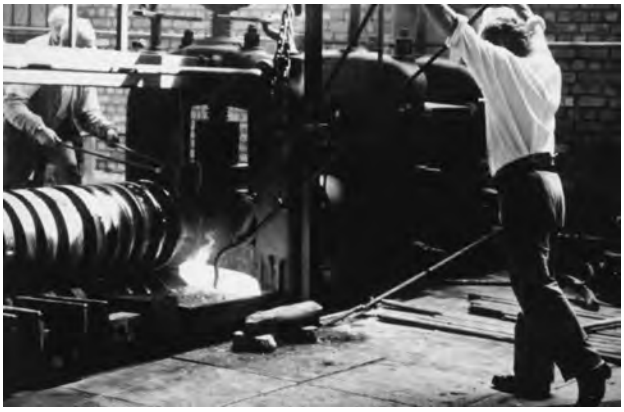

Figure 5. Wrought iron making at Blists Hill.

of Britain, with a long history of mining for copper and tin going back over 3,000 years. During the last 400 years there has been major deep mining for these metals, the technology of which has influenced mining throughout the world. It was here that Richard Trevithick developed not only the high pressure steam engine for mine pumping and winding but also the first use of steam for road carriage and later for rail transport. The mining industry basically collapsed around the turn of the twentieth century with many Cornish Miners going to work in Australia, New Zealand, America, Canada and Mexico. The ruined engine houses and their mining sites became a symbol of the heroic efforts of the local miners. Whilst some mines extended on through the twentieth century, the last Cornish Mine at South Crofty closed two years ago.

I came to Cornwall nine years ago at the invitation of the National Trust, the County Council and three District Councils, together with other local organisations, in order to establish The Trevithick Trust, a charitable Organisation with a membership basis, set up to coordinate, advise and wherever possible manage industrial sites throughout the County of Cornwall. As an educational Charity, our first brief is to educate people about the industrial archaeology of Cornwall, but this obviously must be assisted from tourism revenues. The Directors of the Trust are a combination of people elected by the membership and those nominated by the funding bodies.

Figure 6. Geevor Tin Mine from the air.

We now manage mining sites such as Geevor Tin Mine (Figures 6&7) on behalf of Cornwall County Council, Levant Mine (Figure 8) on behalf of The National Trust, and the Cornish Engine sites at Pool (Figure 9) also on behalf of The National

Figure 7. Mine guide demonstrating at Geevor Tin Mine

Figure 8. Levant Tin Mine.

Figure 9. Cornish Engines.

Trust. We have also entered into arrangements with the Cornish Goldsmiths to manage the Tolgus Tin streaming works (Figure 10) and with Trinity House to manage Pendeen and Lizard Lighthouses (Figure 11).

Whilst most of our sites are mining related, we were also able to rescue the underground museum at Porthcurno devoted to the history of Submarine Telegraphy. This is the major submarine cable

Figure 10. Tolgus Tin streaming works

Figure 11. Pendeen Lighthouse.

landing station in Britain, which was deemed so important during the Second World War that all its activities were moved underground. After spending over £1 million of Lottery cash on this site, we are now looking to extend our brief to look at other communication sites in Cornwall, many of which were related to the early experiments by Marconi in his transmissions both to the Isle of Wight and to America. The Trust is now involved in discussions with British Telecomm to see whether the Trust can preserve the last ship to shore radio site at Land's End which closes this month. Lands End's Radio was an extremely important link between shipping and the UK.

The Trust also looks after the original cottage occupied by Richard Trevithick in Penponds near Camborne, and we are now looking to extend our management agreement for sites in the rest of Cornwall. We aim to establish a network of sites, some large, others small, which will act like a web. The major sites are intended to cascade visitors to the smaller sites and also to the incredible industrial landscape where sites are being restored by The National Trust, local authorities and other bodies.

Apart from hard rock mining, Cornwall is also well known for the extraction of china clay, which is used as a constituent part in ceramic manufacture and also as a filler in paper, plastics, paint, cosmetics, etc. The china clay industry established a museum at Wheal Martyn in the 1970s, which initially was extremely successful but its visitor numbers have declined over recent years. At the beginning of this year the Trustees of Wheal Martyn decided to allow The Trevithick Trust to manage the site on their behalf and immediate action has been taken to turn the site around by creating new displays, advertising the site more widely, and re-motivating the existing staff. Visitors are also able to buy a passport ticket which allows them to visit all The Trevithick Trust sites, including Wheal Martyn, at a discount and this is proving to be a success.

Also during this year the Trust has been involved in a tripartite agreement in order to rescue the important church at St Day. Built during the mining boom of the 1820s, the church eventually became too large for the population, who had mainly emigrated to new mining areas in the New World. By the 1950s the church had become derelict, although local people wished to keep it as a memorial. In 1999 the Local Authority had money to spend on the church and the diocese of Truro wanted to be free of their obligations; The Trevithick Trust intervened as the Organisation that could take on the restoration work using Local Authority funding, liaise with the local population and take on a 25-year lease from the Diocese of Truro. On completion, the church will be used as a performing arts space, under the control of The Trevithick Trust, whilst allowing local people to express their own identity.

Due to the success of the Trust we are constantly being approached by outside organisations in order to become partners in new projects. Current development schemes include Croggon's Tannery at Grampound - the last oak bark tannery in Cornwall - which has been in existence since at least 1714. The owners would like to continue oak bark tanning but at the same time generate additional revenue from visitors and from craft activities. The feasibility study is at present being conducted by the Trust.

A much larger project with which the Trust is involved is the restoration of Perran Foundry, close to Truro, which during the 19th century was one of three large foundries and engineering works in Cornwall that made the massive beam engines and pumping machinery required for a world market. The scheme at Perran is costed at over £8 million. The foundry itself closed in the 1870s and is of considerable historical importance as very few foundries have survived unaltered since that date. The problem here is that whilst part of the historic works will be preserved and interpreted by The Trevithick Trust, the rest of the site will be used for retailing and catering, which means that public bodies giving money are extremely reticent to support the project as they feel that public money might be going into private hands. The Trust, however, feels no reticence in working with commercial developers if the Trust, as an educational charity, can present its message to visitors who would not normally come near a museum experience.

The secret of our success must be focussed activities based on a small number of dedicated staff who feel that they are responsible for sites throughout Cornwall and with a good mixture of paid staff and volunteers. As Cornwall is an economically depressed area, there is not too much difficulty about obtaining capital grants, with funding from the National Lottery, European funding and Government money. However, the Trust must remain mean and lean as income from visitors will never fully cover the costs of its operation. Its prime objective of preserving industrial sites in Cornwall is being increasingly achieved and having an effect on the way in which Tourism chiefs actually view Cornwall's appeal.

Geological Time and new insights into the Rates of Geologic Processes

Chris Hawkesworth, Department of Earth Sciences, Bristol University, Bristol BS8 1RJ

Time touches us in all sorts of ways, in memory, in grief, and in reminding us to make the most of every day. As Earth scientists it is suggested that we have the inbuilt advantage of understanding the time scales of our origins and of evolution, and as students of natural processes we need an understanding of the time scales, and hence the rates of those processes. The big challenge to Earth scientists is to unravel rates of change from the geologic record.

> '….. what makes the earth sciences so special among the so-called 'hard sciences' is that they share with some of the humanities a fundamental dimension – that of time, and more precisely that of 'long time', as introduced in history, for instance, by H Braudel. It is the ability to measure time, to go from a static to a kinematic and then to a dynamic picture of the earth over time scales ranging from thousands to billions of years, that give the earth sciences much of their attraction for students, and much of their power.'
>
> 'There are at least two key common points to the geo-scientific revolutions: the first is the need for a global approach, the second the importance of time, without which the complex dynamics of the systems cannot be understood. The earth (and the planets) as a whole are the common subject of all studies; earth's behaviour is global, its envelopes are coupled, it has a common history and a single future.'
>
> (Allegre & Courtillot 1999)

It is the improved measurement of the ages of events, and of the rates of change, in the geologic record that has underpinned the current revolution to determine how things happened, rather than simply to describe them. The plate tectonics revolution taught us that we can and should study change itself; it marked a major shift in our focus, from products to process, from descriptions of rocks to what makes rocks (van Andel 1994).

Estimates of the age of the Earth have increased markedly from the few thousand years suggested by Archbishop James Ussher in 1654 to the present estimates of ~4.55 billion years (Ga). On geological time scales not even rocks of ages are static, but the vast amounts of time yield slow average rates of change that may be misleading. Thus, the tectonic plates on the Earth's surface move at rates of a few centimetres a year, and most deformation is concentrated at plate margins. However, at least on the Earth's surface such deformation does not happen slowly. Rather communities living near plate boundaries are at risk from potentially catastrophic earthquake and volcanic events in which large amounts of energy are released in very short periods of time.

Similarly the sedimentary record can appear continuous, but clastic sediments are often deposited in short-lived events (turbidity currents, flash floods). Thus, even a continuous sedimentary sequence may only record the physical conditions prevalent in short lived depositional events, and the vast tracks of time between such events go unrecorded, simply because little or no deposition was taking place in the particular area sampled. In both examples, whether the geological processes of deformation or sedimentation are continuous or episodic depends on the time frame of the description. Over tens of millions of years, the processes appear continuous, and yet on the scale of human life spans, or even millennia, they may be highly episodic. It follows that to understand the mechanisms of how things happen we need to know how fast they took place and so, what we can know from the geological record often depends on how well we can determine time.

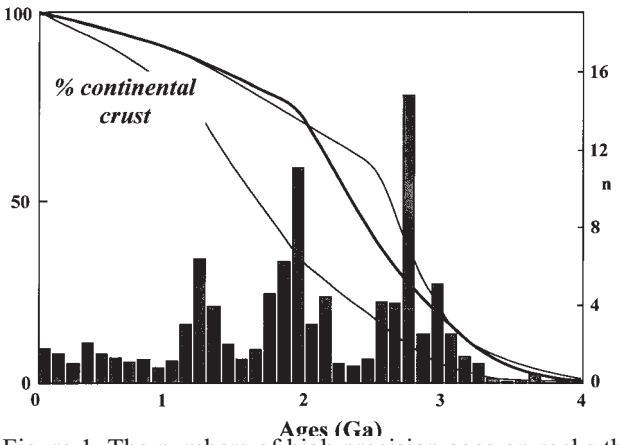

Figure 1. The numbers of high precision ages on rocks that represent new additions to the continental crust from 3.8Ga to the present time. The curves illustrate some recent models for how the relative volumes of stable continental crust have changed with time.

Geochronometers

The primary goal is to obtain precise absolute ages of events in the geological record, and absolute ages are determined using isotopes produced by radioactive decay. Certain isotopes are unstable and the rates at which they decay are known so, if we measure the amounts of the isotopes produced by radioactive decay, the age of the sample can be calculated. The absolute age of the Earth was first determined using the isotopes of U that decay to isotopes of Pb, and they have half-lives of 0.7 and 4.5Ga. Since then a number of isotope schemes have been applied to date different rocks and minerals; they have half lives that vary from ~1 x 10^{-11} to 22 years, and so they can be used to date samples that range in age from billions of years to those formed within the last few decades. One underlying problem is that the errors on measured ages are usually some proportion of the age, and so it is often easier to obtain smaller absolute errors on the ages of geologically younger samples. A second is that precise ages are only really useful if you know exactly what has been dated. That may be a curious point since, if you have analysed a rock, surely the age obtained is the age of the rock. Perhaps, but rocks are mixtures of minerals, and if those minerals were of different ages, what might the age of the whole rock mean? One way round such dilemmas is to date minerals, or even parts of minerals, by new techniques that allow the direct dating of tiny fragments of minerals sampled by lasers, whereupon you have much more opportunity to see exactly what you are dating.

Some examples

There are numerous examples of how improved chronology has changed the way we think about natural processes, and here are just two examples.

In recent times new continental crust has, and is, being generated by magmatism associated with the subduction of oceanic crust along destructive plate margins, and many models for the evolution of the Earth's crust and mantle has suggested that similar processes have been in operation for at least the last 3.5 billion years. Since, in the plate tectonic paradigm, the processes of crust generation and destruction are continuous over long time periods, the prediction is that there should be a smooth continuum in the ages of mantle derived igneous rocks back through the history of the crust. Such ages are plotted as a histogram in Figure 1 and it is a striking observation that the ages define three peaks at 2.7, 1.9 and 1.2Ga. These peaks represent periods in which unusually large volumes of continental crust were generated, and it is difficult to envisage how such peaks and troughs, in the rate of generation of new crust, might be due to changes in plate tectonics. Rather, they are attributed to major thermal upheavals in the Earth's mantle. The implication is that much of the early continental crust was generated by magmatism associated with high temperature mantle plumes and not with the subduction of oceanic crust after all: in intraplate, and not in destructive plate margin tectonic settings.

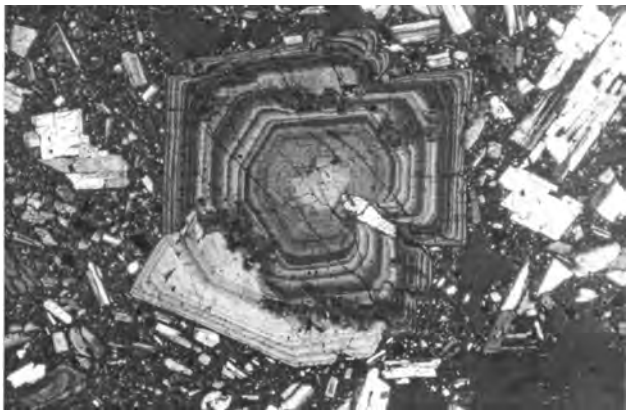

Figure 2. Photomicrograph of a zoned plagioclase crystal.

Figure 2 is a photograph of a plagioclase crystal in a volcanic rock and its complex zoning pattern is testament to the multistage evolution of the magmas it has been in equilibrium with. In many ways such zones in igneous minerals are analogous to tree rings in that they preserve a record of the changing environment in which they grew. The problem is that it is very much harder to calibrate the zones of an igneous mineral, since we know neither when it stopped growing, nor how much time is represented by each individual zone. Yet the timescales involved in the generation of igneous rocks have long fascinated petrologists, and more recently they have become more than simply of academic interest, since they inform models of the causes of volcanic eruptions.

A recent approach has been to use the short-lived isotopes of the U decay series, and these have shown that minerals in volcanic rocks erupted within the last 100 years may themselves be up to 60,000 years old at the time of eruption. So, the time periods represented by crystals of the sort illustrated in Figure 2, may be much longer than we might have predicted, but there is a twist. What we really want to know is not how old the crystals may be, but how long it may take for the processes of fractional crystallisation to take place, not least because evolved magmas typically result in more explosive eruptions. One thing we do know is that

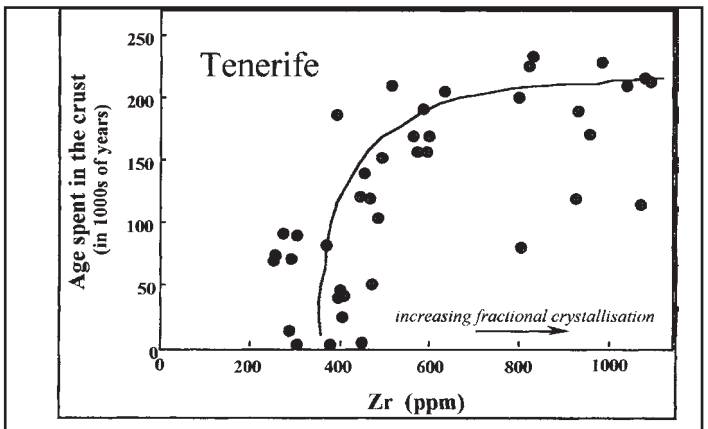

Figure 3. A plot of how long individual magmas (rock samples) have resided in the crust beneath Tenerife in the Canaries plotted against their Zr contents. The Zr content is an index of the amount of fractional crystallisation experienced by the different magmas. The diagram shows how the more evolved magmas (which have 1000 ppm Zr, and represent up to 80% fractional crystallisation) have typically been in the crust for ~ 200,000 years.

the crystals removed in the processes of fractional crystallisation are not those still sitting in our rock sample and available to be dated. So an alternative approach had to be developed in order to determine the age of the magmas rather than the crystals. This has been very successfully used by a young Open University scientist, Dr Louise Thomas, who has shown that it took almost 250,000 years for primitive magmas on the island of Tenerife in the Canaries to evolve to phonolites by fractional crystallisation (Figure 3). Much of the fractional crystallisation took place slowly in magma chambers near the base of the crust, subsequent fractional crystallisation was almost at sea level and was very much faster. In general, the length of time magmas spend in the crust prior to eruption depends on the thickness of the crust, the amounts of extension (if any) and the rate of magma supply from the mantle.

Other areas where there have been dramatic improvements in our ability to determine time from the geological record include using the rates at which trace elements diffuse through minerals in both metamorphic and igneous rocks, and in palaeoclimate studies. The Greenland ice cores have received great publicity, and among other findings they record how the temperature in Greenland dropped an amazing 7 degrees in only 50 years just 11,500 years ago. However, cave deposits (stalagmites and flow stones) preserve even longer records of how the climate has changed, and they are well protected from destruction by natural processes within the cave environment. These deposits often contain small numbers of small pollen grains, and work by a student at the Open University has used this new approach to demonstrate that the climate in Britain from 100-40 thousand years ago was significantly warmer that had been thought previously. All quantitative models (e.g. for the generation of the continental crust, the differentiation and eruption of magma, and climate change) need ever better information of when, and how fast, natural processes took place. The more we learn, the more we appreciate that many big changes in the geological record took place very rapidly, despite the vastness of the Geological Time.

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Book reviews

Life & Death of Coral Reefs by Charles Birkeland (ed), 1997, Chapman & Hall, 536pp, £59.00 ISBN 0412035413.

The enthusiasm for the subject displayed in the first sentence of Chapter 7 is infectious, and I agree with the synopsis on the back of this solid book giving an extremely explicit guide to the contents, culminating with the fact that it will appeal to researchers, undergraduate / graduate students who are involved in marine biology, global environment change, tropical ecology, symbiosis, invertebrate zoology and fisheries management; I would also include Earth Scientists and not just sedimentologists.

During my courses with the Open University, I have been fascinated by the books of colour plates and videos of glimpses into past coral seas, e.g. S236 The Capitan Reef with Dr Peter Skelton, and the video of the Great Barrier Reef, Australia taken as recently as 1998 with the Cairns Diving School, so I was pleased to have the opportunity to review this book, but found this presentation heavier to digest.

A work of some eighteen chapters with 435 pages of text, each with a separate author, it was subdivided on a framework / minited system into eight pages of subheadings to deal with the subject matter of each heading and it represents a serious academic look at coral reef systems. These pages represent a great deal of teamwork drawn together by the editor who wrote the final chapter. This is reflected at the commencement of the book by the full page of acknowledgements for the figures, sketches, photographs and illustrations, all black and white, which follows the eight pages of contents and culminates in eighty eight pages of references cited; an extensive help to further reading. This is followed by a useful nine page index. Doubtless this is now greatly facilitated by increasing global co-operation through the email / internet, which the publishers have accessed.

I reached for my atlas to learn that Guam is a tiny island of the USA sandwiched between the Mariana Ridge and Trench in the Philippine Sea approximately 12°N 145°E. What an interesting place to study Earth Sciences, being volcanically active and experiencing earthquakes of shallow (0-100km) and intermediate (100-300km) depth, adjacent to the trench where the Pacific Plate is being subducted beneath the Philippine Plate (S267 Open University Esso Map of the World) and in the vicinity of real reefs! Contributing authors were from establishments circling the globe as follows; three from Guam, nine from USA , two from Canada, one from Hong Kong, one from Australia and one from Britain; consequently I immediately forgave the alien spellings - favor (p57), neighboring (p30), sulfate (p133), areal (p142) and little "r" was missing (p169 line 7 structure, or was "r" stuc' in the mud! i.e. nutrient excess affects compensation depths). Colourful language caught my eye on p309 line 7.

1 was more reluctant to forgive the alien scientific labeling, e.g. µM, but here I am showing my Open University upbringing, so feel the amateur might have difficulty with p105, or do we calculate IOXE 0 being the power of 1 or is the measurement luminosity! I also assumed 2,500 n. mi. referred to nautical miles squared (p297 top line). Whilst on the subject of coral growth, I find The New International Websters Student Dictionary (1996) p456 shows meter (2) as the basic unit of length [meter (1) being musical] whilst metre (from the Napoleonic French original measure of length supported by physicists, e.g. S102, Open University and A.F.Abbot is shown as "Chiefly Brit"! I did not realise that this was a spoil of the battle of Waterloo! Of my older dictionaries, e.g. The Concise Oxford Dictionary sixth edition 1976, credit for the metric standard measure is given to Napoleonic France or are we all adjusting to scientific changes too (see DDIOO Adjusting to social change). Figure 14 2 on page 306 was not adjusted for epoch duration so that will give readers a chance to brush up on their science foundation course ratios with especial attention to margins of errors!

Each chapter deals with factors that can shift the balance from processes supporting coral reef growth and development to those that result in reef degradation. Increased nutrient input restricts to shallow water the compensation depth (sufficient light for photosynthesis is equal to respiration) of benthic algae. Reefs are sustained by interactions between corals and their symbiotic algae. The book sets out the value of limestone and follows its development from the Paleozoic to modern times. Each chapter then shows the balances that must be maintained and details the following: bioerosion, diseases, organic production / decomposition, production / recruitment, invertebrate predators / grazers and the effect of reef fishes to sustain corals and symbiotic algae with supporting facts and figures.

Indirect interactions are dealt with in great detail to show geographic differences, ecological processes on coral reefs and ecological interactions on the tropical seascape; several chapters draw attention to the scope for further research and there are various methods of analysis and interpretation of the facts and figures. The author of Chapter 10 recommends the reader to an allied book and Chapter 11 has a witty but true (I think) quote. The diversity and distribution of reef organisms and how economical development of recent times can bring about disturbance and diversity of reef organisms, e.g. increased sedimentation due to soil run-off subsequent to excessive logging and interchange of waters, Red Sea opening and Indian / Pacific Ocean waters respectively. The final chapter reviews management solutions and implications for management of resources globally.

Whilst much of the research that went into the production of the facts and figures that support the text of this book was no doubt enjoyable, much must have been tedious and at times very dangerous, e.g. Sea World Research and Rescue: Wild and Dangerous Shark Seas Barrier Reef by Dr Charlie Revon, BBC TV Bristol. I trust that is the reason that the price is roughly twice that of comparable books, though it is well bound.

Such has been the development of research in this field that I find many species, taxa etc. are not to be found in my reference books so that I cannot confirm their accuracy of identification and find it very tempting to head for the reefs! There must now be scope for new specialised dictionaries. I found the method of repetition throughout the book would recommend it as material for Open University reading material at all levels along with surfing the world wide web!

Sheila R David

Discovering Geology: FossiI Focus - Echinoids by M Woods, 1999, BGS, A3 folded, £1.95, ISBN 0852723180.

This is a booklet in the excellent Earthwise publications series and it is illustrated with many clear, colour photographs and is easy to read. The photos show the main features and the varying shapes of echinoids, however, there were no scales and this may mislead the reader. There is an overview of echinoid environments and life-positions and styles, as well as a good description of modern-day echinoids enabling a comparison to be made with fossil echinoids. The booklet also describes how echinoids can be used for biostratigraphy, explaining faunal provincialism and biozones, particularly in the Cretaceous chalk.

I particularly liked the folklore and fact section which would whet the appetite for finding out more. As the title suggests this booklet seemed to be aimed at those who are beginners or those with a smattering of knowledge and, in this, it has succeeded.

Wendy Owens continuing Earth Science student

Fly them or Fry them? How to mix Geology and the Jet Engine

Colin Small, BMet (Hons), MIM. Rolls Royce plc, P.O.Box 31, Derby, DE24 8BJ (and OUGS East Midlands Branch)

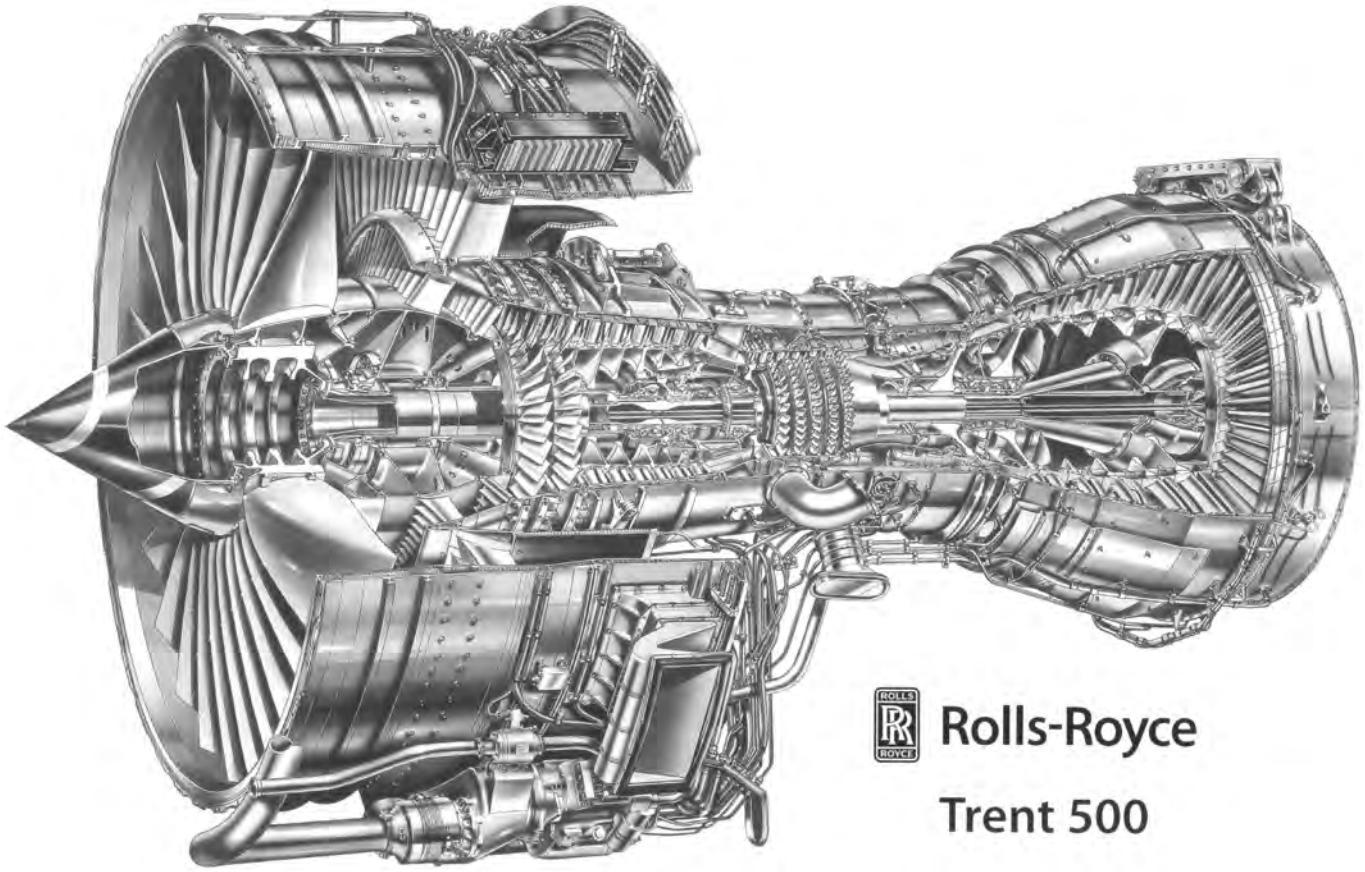

Figure 1. Cutaway section of a typical modern high bypass turbofan. (The Trent 500 will power the Airbus A340-500 and – 600 in early 2002.)

Abstract

Today we all take air travel for granted. You get on an aircraft and 3 or 4 hours later arrive at your destination and do not think twice about the technology that has just got you there. The key to this process is the jet engine, or to give it its proper title, the gas turbine. It hangs under the wings, unseen by most people, has a design life of 10,000's of hours and operates in the most corrosive, abrasive, high stress, high temperature application of any modern machine. It does this safely, reliably and remarkably cost effectively. Yet no one ever asks; How? The intention of this paper is to describe the operation of a modern gas turbine and to show how some of the routine geological problems that it encounters are overcome. It will also show that not all geology is on the ground, some of it is airborne, creating a whole new subject for me to investigate. It is also intended to show how the more unexpected aspects of geology can throw up challenges to modern engineering.

1. The Gas Turbine

The modern gas turbine was invented in the late 1930's by a young RAF officer called Frank Whittle. His original thoughts resulted in the Whittle W1 engine that first flew on the 21st May 1942 in the Gloster E28/39, a very simple unarmed demonstrator aircraft the sole purpose of which was to prove that the gas turbine was a practical means of aircraft propulsion. This was achieved, but it was not until 1944 that a Rolls Royce development of this primitive gas turbine, the Derwent engine, finally went into service in the Gloster Meteors of 616 squadron. (Two useless bits of history: (a) All gas turbines designed and built solely by Rolls Royce Derby are named after rivers and (b) Rolls Royce engines are the only ones that turn clockwise when viewed from the front). This engine operated at a maximum gas temperature of about 600ºC with a thrust/weight ratio of less than 1. The modern gas turbine (Figure 1) is a highly developed descendent of this engine. Its maximum operating temperature is now close to 1400ºC (which is above the melting temperature of some of the metal components in the gas stream) and has a thrust/weight ratio of about 6. To put this in context, to get a Boeing 777 off the ground using Sir Frank Whittle's engine would require 84 under each wing.

The gas turbine has 4 main operating units that equate closely to those in a 4-stroke car engine (Figure 2). These perform the operations of suck, squeeze, bang, blow. Imagine that you are at 40,000ft half way to America in a modern twin engined long-haul aircraft. You are nice and comfortable at 20ºC and pressurized to about 8,000ft. Outside the temperature is -40ºC and the air is unbreathable. Yet the engine works! The fan takes in the air at the

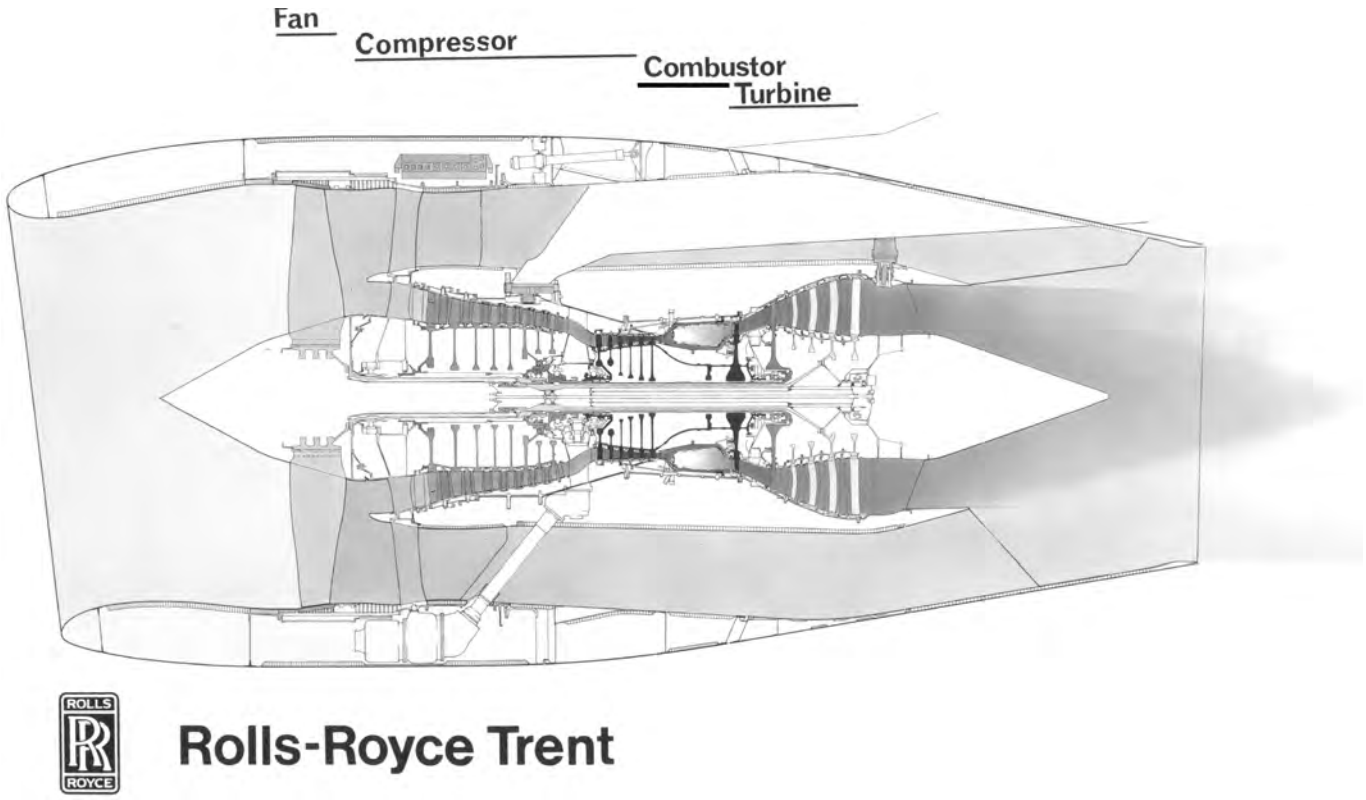

Figure 2. General arrangement of a gas turbine illustrating the 4 basic modules.

rate of about 1 tonne a second; 60% of this air is passed down the bypass duct to provide a quiet, efficient form of thrust. The remaining 40% is passed into the compressor which acts just like a bicycle pump. Over the distance of 5 – 6 ft it compresses the air to 30 times atmospheric pressure. In so doing the air heats up to around 600ºC (think of your cycle pump – the hose connected to the tyre gets hot because you have compressed the air) and is delivered to the combustion chamber. This is effectively a high technology baked bean can that has lots of holes in it. On the central axis fuel is burnt while passing a lot of relatively cool (600ºC) air around the chamber to keep the flame away from the metal. This is necessary as there is no known material that can survive direct exposure to the flame for the design life of the engine. Burning the fuel heats up the compressed air and causes it to expand. This hot expanding air is exhausted out of the back of the engine to provide the forward thrust and power to the aircraft. Unfortunately in order to power all the turbo machinery at the front of the engine we have to extract energy from this hot corrosive gas stream by putting turbine blades (Figure 3) into it. These are forced to rotate by the action of the gas passing over them and through a system of shafts and bearings rotational energy is delivered to the fan and compressor thus keeping the engine operational.

The system is very effective but has a number of problems. For this discussion two of the most important are:

1) The gas temperature is above the melting temperature of the metal blades

2) The amount of air coming into the engine makes it the worlds most efficient vacuum cleaner

The former is overcome by passing cooling air from the inside to the outside of the blade through a network of small holes. This

Figure 3. A high pressure turbine blade from an RB211-22B engine.

Figure 4. A Saudia Airlines Lockheed Tristar landing on a dusty day at a desert airport.

keeps the hot gas away from the metal and allows it to survive in this aggressive environment. The limitation of the solution is that if the holes are blocked the cooling disappears and the blade melts, usually in a few seconds. The latter is the problem that this paper is about. You can forget the bits of aircraft, bolts etc. that get sucked up by engines around airports; we are concerned here with the dust and geology that becomes airborne and enters the atmosphere.

2. Routine Geological Problems and Solutions

A new gas turbine blade looks like the one shown in Figure 3. It is about 100mm tall, weights about 200g and costs £500 to make. The grain structure is clearly visible as are the series of small holes that allow the cooling air out to protect the blade. Unfortunately in normal operation the engine swallows large amounts of dust (Figure 4) and this is deposited on the turbine blades as an orange/pink scale (Figure 5). As can be seen this blocks the holes, which then fail to provide the cooling air. The blade then overheats and melts and the engine is damaged or, on a bad day, destroyed. Airlines do not like this, passengers have to be looked after until a new aircraft can be found and the repair bill is not cheap. My job is thus to help to answer the following questions about these deposits:

1) What are they?

2) How did they get there?

3) What do we do to stop it?

The aim being to answer question (3) and stop a lot of agression and cost. This involves the use of X-ray diffraction which enables identification of the deposits by recognising their crystal structure. Once this is done the answer to question (2) can be deduced and hopefully a solution put in place. What follows are two examples of this problem from different parts of the world.

2.1 Arabian Sand

Fairly soon after Rolls-Royce sold its RB211 engines to airlines that operate in the Middle East the turbine blades started to fail after unusually short lives. Examination showed that this was due to blockage of the turbine blade cooling holes by a thick, adherent orange/pink deposit (Figure 5). This has two major constituents:

1) A fine, smooth, pink deposit over most of the blade aerofoil, root platform and root (this appears as a smooth light grey film on the blade in this photograph)

Figure 5. A high pressure turbine blade from an RB211-22B operated in the middle east. The smooth grey deposit is in reality pinkish, the coarser deposit is a red/orange colour.

2) A much thicker, light red-brown deposit exclusively on the central areas of the aerofoil (the rough darker grey deposit)

This was therefore presented for analysis with the three classic questions already described.

X-ray diffraction analysis quickly identified the following constituents. The fine pink deposit was anhydrite ($CaSO_4$). The thicker light red/brown deposit was a complex calcium magnesium silicate with a diopside-type structure and in both cases small amounts of iron oxide (hematite – Fe_2O_3) and quartz (SiO_2) were always present. Depending on operator and area of the blade sampled, small amounts of dolomite ($(Ca, Mg)(SO_4)_2$), halite (salt – NaCl) and various feldspars were also occasionally seen; quite a witches brew! From the analysis it was obvious that the deposits originate outside the engine and the prime candidate for the origin was ingested airborne debris. Such ingestion routinely occurs on take-off and landing (Figure 4) or on passing through dust storms. Samples of the runways and deserts in the Middle East were therefore requested.

Problem! You are not allowed to export sand from Arabia without a permit. No, it's not that they do not have enough sand but it is necessary to protect archeological artifacts. It is a slow process to obtain the permits and can take a lot of time and effort. Meanwhile aircraft engines continue to fail. So, enter the cloak and dagger department. Engineers all over the Middle East were

Figure 6. A sample of the runway at Abu Dhabi. (Yes - those are sea shells and the small black lumps are tarmac).

asked to 'sweep up' samples while they were on the runways, empty their car air filters and even take samples off the tyres of recently arrived aircraft and send them in for analysis. A typical sample is shown in Figure 6. These were subjected to the same X-ray analysis as the engine deposits and were found to be made up of:

1) Quartz in large amounts (Newsflash - Analysis by Rolls Royce proves that deserts are made largely of sand!)
2) Calcium sulphate (usually as anhydrite but occasionally gypsum (hydrated calcium sulphate – $CaSO_4.2H_2O$))
3) Hematite
(4) Calcite and aragonite (calcium carbonate – $CaCO_3$)

Other minerals were also found (dolomite, halite and feldspars) but these were always in small amounts and they were not always present. If you ignore the sand, this analysis obviously links the majority of the engine deposits and general surface geology of the Arabian desert near the airports. But what is the mechanism? To work this out I took a visit to the library and my first introduction to geology.

The shallow seas of the Gulf region have led to the formation of substantial marine carbonate deposits which are driven onshore by the prevailing winds and wave action. The resulting sediments and windblown sands are subsequently exposed to chemical reactions which result in the formation of significant amounts of very fine forms of anhydrite, dolomite and gypsum. Also, the oxidizing nature of the environment means that ferromagnesian minerals (from any volcanic rocks in the area – the Red Sea rift certainly) and steel from human activities is being oxidised to iron oxide. Subsequent wind action picks up the desert surface and sorts the material. The relatively coarse sand falls back to earth quickly but the fine sand becomes airborne to be ingested by the engine.

So there is a viable mechanism for explaining the anhydrite and hematite - but what about the diopside and what is causing the blockage? There are two possible mechanisms for the formation of this material. Either it originates somewhere else and becomes

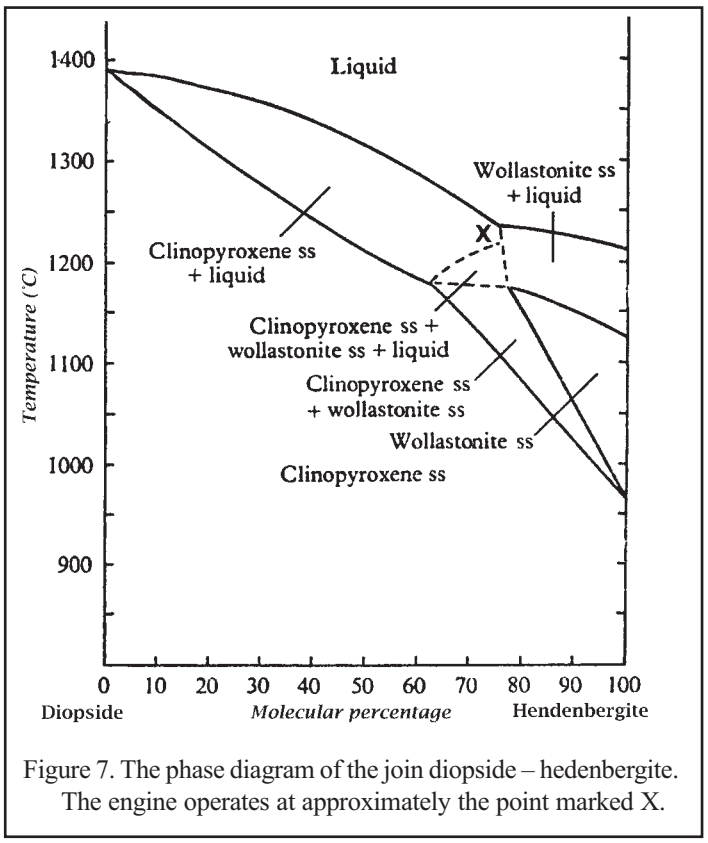

Figure 7. The phase diagram of the join diopside – hedenbergite. The engine operates at approximately the point marked X.

concentrated in the engine, or results from the engine modifying some other silicate material. We know that there is some silicate material present, sand, and the engine is running in a silica-containing environment so the latter seems the more reasonable mechanism. A bit of detective work with a book of mineral phase diagrams, a look at the temperature of the engine and the mixture of minerals likely to be airborne and the solution was obvious. The fine airborne mixture of minerals the engine was ingesting was entering the combustion chamber where it was partially reacting to form diopside. This was then being sprayed at the turbine blade where it stuck and blocked the air cooling holes. So we had a viable mechanism that matches the observations and the analysis, but why does it happen and how do we stop it? This took a bit more detective work.

The fact that diopside was forming in the engine caused us to take a closer look at the characteristics of this material and the exact temperature regime on the turbine blade. Samples of the diopside on the turbine blade were removed and their chemistry and melting temperature were determined. It was shown that the material forming in the engine melted at approximately 1240ºC and, according to the phase diagram, the material would be partially molten and partially solid (Figure 7), a sort of 'hot porridge with lumps'. This very sticky material was being sprayed at the blades and sticking in the very hottest parts of the blade, *cf* Figures 8 & 5. The relatively cool regions are too cold to allow the material to stick, instead it freezes and immediately falls off, so the problem is confined to the hot areas of the blade. We now knew what was going on; the problem was the airborne fines from the desert surface being ingested by the engine where they melted and reacted to form a sticky silicate compound that stuck to the hot areas of the turbine blade. This blocked the cooling holes and caused premature failure. But you will have noticed that the third question has not been answered; How do we stop it?

Figure 8. Temperature contours of a typical turbine blade. The hottest regions are marked G and the cooler regions T. *cf* with Figure 5.

Sand filters are not practical on engines of this size. They work on helicopter engines as these require much smaller amounts of air. But how about in large quantities? Remember the engine is using 60 tonnes of air a minute. The filter would be too big and become blocked very quickly. Don't fly there? That would work but is not a feasible answer for those that need to travel in the Middle East. The answer came from looking at the phase diagram. If you look at the area on the diagram where the engine is operating it is very close to the region of pure liquid. By pushing up the temperature of operation into this region we can change the characteristics of the diopside. Instead of a sticky mixture that is only partially melted we can make the diopside fully molten. It thus still forms in the combustor and lands on the blade, but it now is so hot that before it solidifies the cooling air from inside the blade punches its way through the liquid and keeps the air cooling hole clear. The blade still gets covered in diopside but the cooling mechanism still works. The material of the blade is thus protected and the engine continues to work.

This was the solution that was implemented on the big turbofans like the RB211 and Trent and it continues to work today. The key is run the engine hot! That does bring in other problems, some of which have recently become geological again, but that is another lecture.

2.2 Refractory Australian Dust.

The preceding section has shown how geology can suddenly throw up an engineering problem; something that it continues to do. The effects of sand ingestion into engines still continue in the Middle East; however, the problem is not confined to just this region. It is world-wide in scope and has different aspects depending on which region of the world the engine is operational.

The first warning is the failure of an engine component. In this case from Australia, the warning was burnt-through turbine blades. Inspection quickly showed that the cooling holes were being blocked, but they were not being blocked by material sprayed at them from the combustor. They were being blocked by a white, crystalline deposit with orange/red streaks that was building up inside the blade. The cooling air inside the blade is taken from the compressor so the evidence again pointed to airborne, geological contamination. X-ray diffraction analysis showed that the deposit contained hematite and anhydrite (hence the orange/red coloured streaks) but the surprise was that the white material was aluminium oxide (Al_2O_3). This is not a common mineral to find; it normally occurs as lumps of corundum, which stand no chance of becoming airborne. Again the solution lay in a detailed analysis of the Australian outback in the region the aircraft flew in. It turned out that although the desert is largely sand (more good news – analysis by Rolls Royce shows that sandy Australian deserts are the same as sandy Arabian ones – they are mainly made of quartz!) but there is a small amount of very finely divided aluminium oxide present. Preferential wind sorting selects this fine fraction, hence the problem. However, notice that hematite and anhydrite are again significant constituents. This is something that is true for all engine deposits taken from around the world and is something that I have never satisfactorily explained to myself.

The solution in this case was not as simple as raising the temperature of operation of the engine. Aluminium oxide is extremely refractory and relatively inert. Also the problem was that it was coming into the engine, not that it was reacting. So the only viable option was to redesign the cooling air system to cope with the build-up of the material. An expensive option for RR but the only one that would work in the circumstances.

3. The Unexpected Problems of a Volcano.

The problems of deserts continue today, however, in the last 20 years a new and growing problem has started to appear – volcanic dust. This has become a problem because there is a growing demand for air travel which results in more aircraft in the sky. The chances of encountering a volcanic cloud are therefore much greater and the damage they can do is immense.

3.1 The Mount Galungang Effect

In June 1982, a British Airways Boeing 747 was traveling at night near Bandung, Indonesia, on its way to Australia. The passengers were asleep and the flight was proceeding uneventfully when a burning sulphurous smell was noticed in the cabin. All 4 engine stopped and the aircraft dived from 35,000ft to 5,000ft in a couple of minutes. The passengers were now very much awake and becoming seriously impressed, not to say panicked, by the behav-

ior of the aircraft. The cabin smelled of sulphur, St Elmos fire could be seen out windows and it was obvious that the aeroplane was going down, fast. Fortunately the engines restarted and the aircraft started to climb. The captain worried by what had happened diverted to a near-by airport only to have all 4 engines stop again. The aircraft again dived as it had no power and the passengers were by now seriously impressed by the problem. But on getting to lower altitudes the engines again re-started and the aircraft attempted to land. Unfortunately the pilot discovered that he could not see the runway and had to land using only his instruments. It was only when they got on the ground that the seriousness of the problem was appreciated. The damage was enormous, the paint was stripped off all the forward-facing parts of the aircraft, all the windows were etched to a frosty finish and the engines and all aircraft systems were full of black dust and lumps of a glassy material.The aircraft was effectively scrap.

It transpired that the flight had encountered the eruption cloud from Mount Galungung. As it was night the fine volcanic ash was not visible, it was also invisible on radar and the first warning the pilot had was when his engines became clogged with dust. The dust also melted in the combustion chamber and was sprayed at the turbine where it cooled rapidly to form obsidian. Fortunately, as the aircraft dived it exited the cloud, removed the dust problem and the cooling of the engine caused the obsidian to crack and fall off. Clean air could thus enter the engine, the turbine cleared sufficiently to run and the engine could be restarted. After the first engine shutdown turning back and climbing (a pilot's normal reaction) was the worst thing he could do. The aircraft climbed straight back into the cloud and went through the same process again.

This is rather a dramatic illustration of the problem a volcano can cause (so much so that one of the passengers wrote a book about it) but it is not an isolated incident. Near Mount Redoubt in Alaska in 1989 a KLM flight also lost all 4 engines in a similar manner, and at Mount Pinatubo in 1991 14 aircraft flew into the cloud. Warnings about volcanic clouds are given but their exact path is difficult to predict and they cannot be seen on radar or at night. So, what can be done?

Prediction of the extent and path of dust clouds is obvious as is a detection system for this type of hazard. Unfortunately prediction is not 100% foolproof and the detection system for aircraft does not yet exist. Understanding the behavior of engines and airframes in such an environment to make them more tolerant of such encounters is thus underway.

3.2 Testing Volcanoes

So, how do you test the effects of a volcano on an engine? The answer is very simple you run an engine on a test bed and introduce volcanic dust into the air the engine uses. You can then observe the effects on the engine and test modifications. Unfortunately the standard material to use for these ingestion tests is soil derived from Southern California, a sand/clay mix derived from weathered decomposed granite. It is not very like a volcanic dust! So, what could we use, and why? The requirements for any valid large scale testing are that the material used must be readily available, uniform, cheap (an over-riding criteria in industry), easy to get at and representative of a typical volcano. Two sources have so far been identified:

1) Twin Mountain, Des Moines, New Mexico – 85% basaltic glass, 15% plagioclases and pyroxenes.
2) Mt St Helens – 25% basaltic glass, 75% plagioclases and pyroxenes.

These are now being used to test engines and seem to give results that mimic the effects of real volcanoes on real engines. However the search is not over. We are still looking for sources of volcanic dust and looking to see how different they are. This is an interesting diversion for me in my daily job as I get to look at geology while working. I have recently been looking at the dust from Montserrat – an aircraft flew into the dust cloud while flying 3000 miles from it! I got both the bits and a bag of dust to look at.

4. Summary

I hope this paper has shown you how a jet engine works, some of the problems that airborne geology can cause and how a working knowledge of geology can help not only to identify the problem but also contribute to finding a solution.

5. Postscript

One of the questions that has always bothered me about this subject is why the mixture of minerals that a gas turbine ingests always contains significant quantities of anhydrite? The other major mineral is easy; we live in an oxidizing world therefore the weathering products of ferromagnesian minerals, and the refined iron we use, are iron oxides, one of which is hematite. But anhydrite? I'm not aware of large amounts of anhydrite uniformly distributed around the world, yet it is always either dominant or second in terms of the amount present. So where does it come from? A discussion in the bar at symposium planted a thought. I cannot prove this but it is an interesting theory:

Anhydrite is not widely dispersed but limestone is. Limestone is $CaCO_3$ which will react with sulphuric acid to form anhydrite and gypsum. Suphuric acid is normally present in the atmosphere, both from volcanic sources and from human activities, by the action of sulphur dioxide dissolving in water. Hence the amounts of anhydrite seen in the engine are the result of dissolution of limestone at the surface. As I said I cannot prove this but it is a plausible theory that matches experience.

Acknowledgments

My thanks are due to Rolls Royce for allowing me to use company data; also to Katherine Clay and Colin Baxter within the company who laid the foundations of the X-ray crystallography upon which this work is based and provided the many useful hours of discussion that helped us to arrive at the correct answers to solve the problem.

My thanks are also due to the to the OU and my many friends that I have in the OUGS. All those conversations, lectures, and field trips do make a difference to an amateur. Keep up the good work.

Monitoring the Landslide at Mam Tor - some recent results

Chris Arkwright BA Hons (Open) MSc (Manchester)

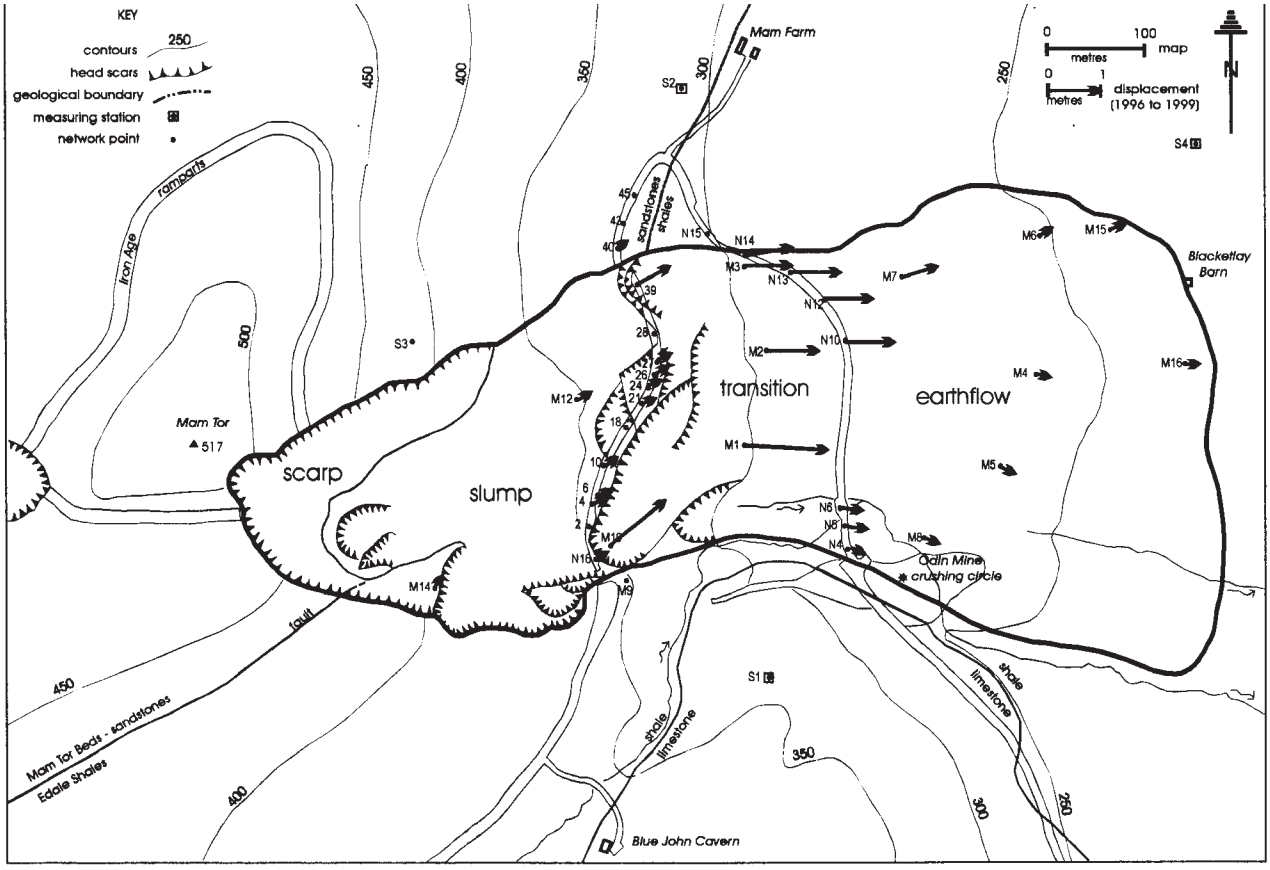

Figure 1. Map of Mam Tor monitoring network

The aim of my MSc thesis was to set up a measuring network on Mam Tor landslide and test the feasibility of long-term monitoring. A network of 36 points was installed in 1996 and their positions surveyed to obtain datum points against which future movement could be measured. Statistical tests subsequently performed on the data confirmed that it was indeed possible to detect movement to a reasonable accuracy by means of an EDM survey, thus long-term monitoring was feasible (Arkwright 1996). The network continues to be measured in April each year and the results are illustrated in Figures 1 & 2 where all movement is with respect to the datum of the 1996 bearings of all points in the network.

Minor movement in an easterly direction was detected on 7 points after the first re-survey in 1997. In 1998, 21 points were judged to have moved but again in a minor way. However, after the 1999 survey it was clear that slippage was up to six times that recorded in the previous two years. Furthermore, this major movement occurred in most parts of the disturbed material suggesting that the main basal slip plane may have been reactivated. The greatest movement was in the transition zone across the middle of the landslide where the ground surface is steeper than in other parts of the network and is consequently less stable. In contrast, the earthflow section below the lower road has a more gentle gradient which is nearer stability and so points in this area have not moved very far. Some *en echelon* cracking of the road surface indicates that the movement appears to be more rapid in the northern part. All these observations imply progressive steepening of the central transition zone which will in due course provide increased driving stress on the earthflow section at the bottom of the landslide.

Results to date in this project correspond well with the pattern of movement observed in a major investigation of the Mam Tor landslide which took place in the 1980's (Skempton *et al.* 1989). It was then noted that a high winter water table accentuated by heavy rainfall in January to March constituted ideal conditions for movement since the higher pore water pressure weakened the rocks below the water table. Rainfall data obtained for the period 1996 to 2000, together with the movement reported above, clearly substantiate this hypothesis. Skempton *et al* (1989) concluded that the landslide had slipped initially about 4000 years ago and would reach stability in approximately 2000 years time. Meanwhile monitoring continues with the support of Professor Ernie Rutter and the help of co-workers David Waghorn, Earth Sciences, University of Manchester and Rob Holloway, Geological Survey Unit, University of Manchester during the annual re-survey.

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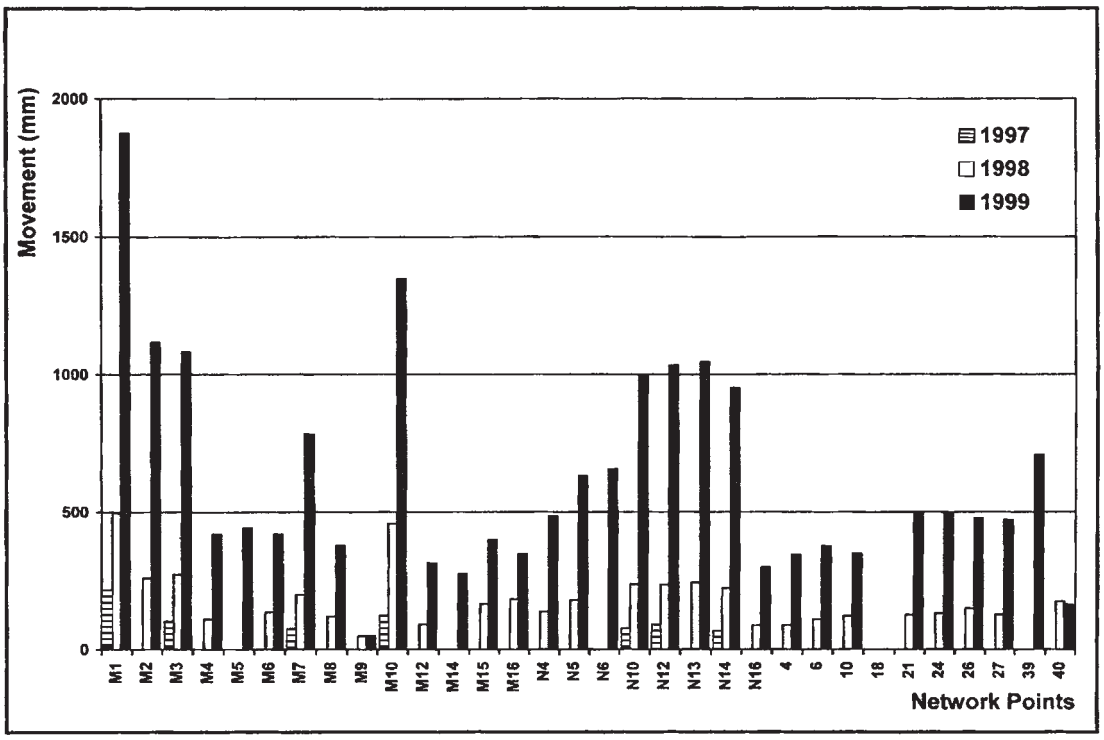

Figure 2. Movement with respect to 1996 Datum Readings

Book reviews

UKESCC Courseware CD ROM, 21 modules, £30 each to students.
It is amazing how much the use of multimedia educational material on CD ROM has progressed in the past few years. One of the first producers of the genre was the well funded Earth Science Consortium using the fledgling Macromedia authorware. It would be easy to criticise this CD, still sold to OU Students, as 'old' because of the assumed age of presentation from an industry where anything over three months old is ancient and up for replacement, but it is not the presentation which should be examined but the content and novel teaching methods. These had to be learned by the people producing the modules. Please don't look for the whizbang approach, nor the flash colours, nor the groovy sound effects, but instead a solid introduction to a variety of geological, and sometimes quite difficult techniques. The modules cover many aspects of geology and are written with a differing and developing student skillset in mind.

All of the twenty-one modules intersperse teaching text, illustrated variously by diagrams, graphs, animations or photographs and questions to see whether what they have been trying to say has sunk in. They have been produced by a range of universities. As with all teaching media the success rate varies, not always with difficulty of concept. As with all new projects the success rate of implementation of (teaching) concept varies, with one module utilising extensive clip-art input while others have obviously not been as pushed for time during the production and have used newly constructed graphical material.

Such a module of the latter sort is the one on Oceanic Crust and Ophiolites, produced by the University of Leeds. Delving deep into it, the subject of overlapping spreading centres and propagating rifts leads into the development of microplates and illustration of these by both diagrams and remote bathymetry. In the same section, questions on spreading rate and topography give instant answers - and lead one to the next subject having ensured, as much as is possible, that the lead-in has been understood.

As always, there is a however. In the original project the format was decreed, and the format of developmental software has moved on. Only by significant continuing investment in skill development (the cost factor is becoming less important) can the consortium compete in an increasingly competitive market. This said, the modules retain their value at the price offered to OU students, but other competing products are coming along into the academic market. Whether they are as good remains to be seen.

John Colby BA Hons (Open)

Early Vertebrates by Philippe Janvier, 1996, Oxford University Press, 393pp, £85.00 (hardback) ISBN 0198540477.
Despite its non-specialist title, this is a very specialised book. Written for the researcher in the specialised field this is not a book that can be read from cover to cover, but just dipped into when specific information is required.

The first two chapters describe early vertebrates as we imagine them, mostly fishes from Ordovician sediments and the fragmentary remains from which whole animals are reconstructed. The countries of origin of the specimens and how they are collected and preserved is described and lavishly illustrated with line drawings of the creatures and their assemblages. The following two chapters are a survey of extant vertebrates followed by a very long chapter on "Early vertebrates and their extant relatives". Each morphology is described, class by class in great detail, much of it at the histological (microscopic) level, again lavishly illustrated. At the end of each section a cladogram defines the relationship of the families within each class.

The following three chapters build on the previous two and discuss "Interrelationships of the major craniate taxa: current phylogenic theories and controversies", "Anatomical philosophy: homologies, transformations, and character phylogenies" and "Evolution, palaeobiogeography and life history". Chapter 8 is a very readable account of the history of research on early vertebrates in various parts of the world. The Epilogue comments on some inconsistencies highlighted in previous chapters and the very extensive reference list covers 60 pages. An excellent reference book - but essentially for the specialised researcher.

Jane Clarke MPhil (Open)

Cottages & Cottagers: One aspect of the "Great Rebuilding of England"

Jennifer S Holt BSc (Open), PGCE

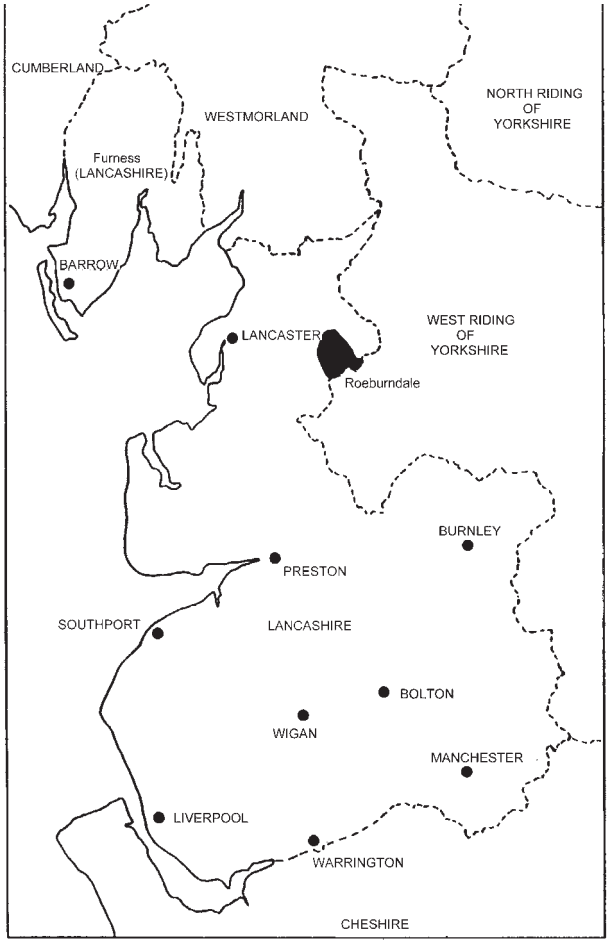

Figure 1. County boundaries before 1974

Roeburndale lies to the east of Lancaster (Figure 1), an area of about 3,500 hectares in a vaguely rectangular shape with the river Roeburn and the Kings Highway running its length from south to north. It was formerly the Chase or forest area for the Manor of Hornby; the term "forest" denotes a legal status rather than dense woodland and for some forests it is clear that there are more trees in the year 2000 than there were in 1500. 1500 is frequently taken as the divide between late-medieval and early-modern; my own researches broadly cover from 1550 to 1850 and so examine both the early-modern and late-modern periods.

The general view, based upon a number of case studies across England, is that in such forest areas the population was still relatively low in 1500 but grew quite steeply (albeit spasmodically) over the next two hundred years, normally peaking about 1700 then either declining or growing further depending upon whether or not the area under investigation became fully industrialised - for we start at a date before industrialisation. There was industry in 1500, people needed clothes and goods made from leather, wood and iron but much of this manufacturing was done in rural settings close to the point of sale and a commonly used term for this is proto-industrialisation.

The population growth is linked not only to the development of industrialisation but also to the maturing of a market economy. An economic surplus was generated and, in simplistic terms, if the person doing the work got most of it then there would be a different result from a situation where someone else received it. In either case, one effect was the replacement of existing buildings by newer ones (Figures 2 & 3) which reflected both changing needs (think of how modern housing estates differ from the mass building of the 19th century - bathrooms, central heating, double-glazing, garages, one bedroom per person) and new building materials.

Figure 2. Good building stone is never wasted; this lintel, with its fancy detail, was part of a seventeenth century building, now replaced by a nineteenth century field barn.

This great rebuilding was first discussed by W G Hoskins, a name revered amongst landscape historians as the initiator of our craft and mystery. Many of his ideas have been refined or even superseded but his writings, now half a century old, were a seminal influence on myself and many, many others.

The Great Rebuilding started about 1550 and finally affected the whole of England as areas saw their historical traditions of cob, timber or cruck framed buildings replaced by new types with new materials. These new buildings appeared earlier in some places and later elsewhere in a complex response to changes in society and to localised economic growth. Some of the earlier buildings were never replaced, as they still answered the needs of society, or were incorporated in later buildings (Figures 2 & 4). The materials with which the new buildings were constructed varied - as the geology of England varies - but the new and much greater demands made upon these resources drove economic growth as brick pits were dug or stone was quarried.

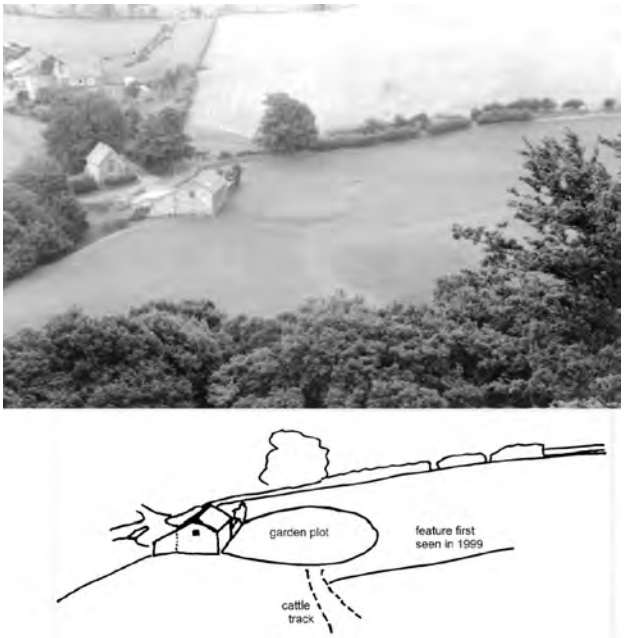

Figure 3. The fieldbarn stands on the site of a farmhouse referred to in the 1582 Survey; its garden plot can be clearly seen. The wide track leads down to the river and may have been formed by cattle from the thirteenth century vaccary as they moved from grazing areas to the water. The feature was seen for the first time in July 1999 when conditions were just right and may be a footpath or a boundary ditch.

These are the broad, national pictures - but one thing we have learned over the last fifty years is that the broad and national pictures never quite seem to fit when applied to a specific area. The first detailed picture of Roeburndale is contained in the 1582 Survey of the Honour of Hornby estates commissioned after the death of William Stanley, Lord Mounteagle by his son-in-law Edward Parker, Lord Morley. (As an aside, it was William Parker, Lord Mounteagle, Lord Morley's son, to whom the warning letter regarding the Gunpowder Plot was sent in 1605). The original Survey of 1582 survives only in fragments but an edited copy was made in the 1670s when the then Lord Morley and Mounteagle

Figure 4. The timbers were cut elsewhere, marked by the wright, then moved to the assembly site. This timber came from an eighteenth century barn and the "E" with four horizontals is clearly seen.

was in financial difficulties, and one copy of this was published in 1939. The Survey shows a number of interesting things about Roeburndale: the number of households totals thirty two (there were also two other farms which did not belong to the Manor of Hornby at this date and probably represent at least another three or four households). So, in 1582 there are some thirty four or more households spread across a range of farmsteads and cottages. One hundred years later the Hearth Tax Returns give the greatly increased figure of forty seven so there is a match here with what I said earlier about the population growing steeply from 1500 to 1700. Table 1 below shows the available statistics for the number of households for Roeburndale, many of the sources used are extremely hazardous to work with but the figures can be taken as minima; Figure 5 below shows the results when graphed.

Table 1. Numbers of households within the Township of Roeburndale

Year & source	No of households
1582 Survey (minimum number)	34
1664 Hearth Tax (includes exempt)	47
1666 Hearth Tax (excludes exempt)	41
1673 Hearth Tax (excludes exempt)	41
1696 Lancashire Association Oath Rolls (minimum number)	39
1700 Manorial tenant list (minimum number)	38
1730 Land Tax Assessment (minimum number)	31
1789 Land Tax Assessment (minimum number)	26
1811 Census (actual number)	39
1821 Census (actual number)	37
1841 Census (actual number)	31
1851 Census (actual number)	33
1861 Census (actual number)	23
1871 Census (actual number)	22
1881 Census (actual number)	21
1891 Census (actual number)	21

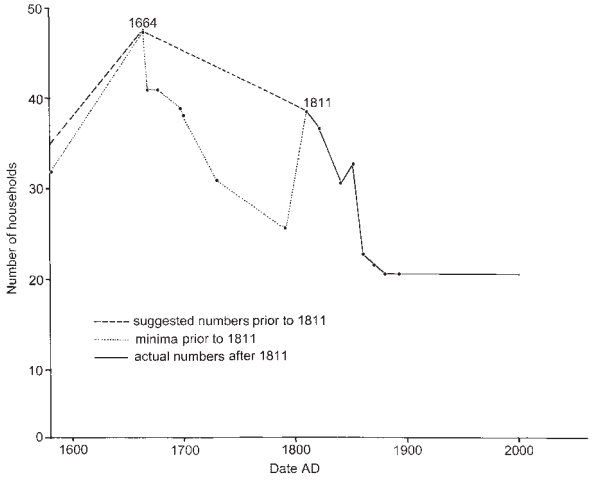

Figure 5. Graph of the households within Roeburndale Township between 1580 - 2000.

The solid line shows the number of households derived from the minima in Table 1. The dotted line is the suggested actual number based on interpretation of the sources used to compile Table 1.

Figure 6. Coppiced trees were trimmed at regular intervals to just above ground level and provided bark for tanning and timber to make into charcoal for iron smelting.

The second feature to emerge from the 1582 Survey is the number of cottages in Roeburndale. The amount of land held and the nature of the tenure (freehold, tenant right, copyhold etc) gave status to the individual but (and this was the purpose of the Act of Parliament which regulated the buildings of dwellings at least until well into the eighteenth century) too little land meant that the household occupying the dwelling might not have sufficient food to support themselves and so could become a charge on the parish or township. Consequently cottages with less than four acres were illegal unless there was a non-agrarian way for the occupants to earn a living and, here, we return to proto-industrialisation.

Four hundred years ago the number of households in Roeburndale was some 50% higher than today and was moving towards its peak. Of this population, 24 households are known to have lived in farms whilst 8 households lived in cottages - a very high proportion. My thesis is that by the mid-sixteenth century, far from being a sparsely populated and principally agrarian area, Roeburndale was fully exploiting its very wide range of resources. This is why there were so many cottagers and this exploitation generated an economic surplus that, in some cases, was retained by the cottage occupants, but in others was transferred to the cottage landlords. Indicators for this retention of the economic surplus can be found by examining the evidence of the great rebuilding of cottages within Roeburndale. All the cottages were abandoned by the 1850s when the arrival of the railway finally destroyed the demand for Roeburndale's stone, coal and iron.

Appendix 1
By-employments in Roeburndale

It is extremely difficult to identify just what people were doing in the late sixteenth century; however, for the late seventeenth century a very wide range of documents gives the evidence to show that the people of Roeburndale had an enormous range of by-employments (that is, employments carried out alongside "farming" by either the "farmer" and/or members of the household). The use of a combination of parish registers, court rolls, wills and inventories, diaries etc generate the following list for a period roughly 1670-1700:

coal mining
stone quarrying (both walling and roofing stone)
charcoal burning
iron smelting
spinning & weaving
cheesemaking
leatherworking
woodland management to produce:
- timber
- wood for charcoal
- wood for barrel making
- bark (for tanning)
- basket making

Author

Jennifer has a BSc (Open) in Earth Sciences and is now doing a PhD at Lancaster University in Landscape/Economic history.

Book review

Earth Science Teachers' Association – Investigating the Science of the Earth: SoE1 Changes to the Atmosphere; SoE2 Geological Changes – Earth's Structure and Plate Tectonics; SoE3 Geological Changes – Rock Formation and Deformation, ESTA, 1995-1998, £3.50 each from Geo Supplies Ltd., 16 Station Road, Chapeltown, Sheffield, S30 4XH.

I rather like these! Especially the bit in SoE3 about using a well-shaken bottle of champagne to demonstrate the lava froth produced by degassing! Apparently the results are much superior to those produced by lemonade. (I bet all those Grand Prix winners never realise they are demonstrating geology!)

This is a series of 3 books aimed at teachers delivering the National Science Curriculum at Key Stage 4 (GCSE) to 14-16 year olds, although some activities can be adapted for use with older or younger pupils. Editors are Chris King of Keele University's Education Department and Peter Kennett of High Storrs School, Sheffield. The books can be obtained from GeoSupplies Ltd at £3.50 each.

Each volume includes a series of 10 activities, which are presented as an A3 double-spread, with additional diagrams and worksheets. One great advantage that is offered is that copyright has been waived for classroom use.

SoE1 includes activities about the water and carbon cycles and temperature and climate changes; SoE2 looks at density, seismics, sea floor spreading and magnetic stripes plate motion and continental drift and SoE3 at rock types and processes, the rock cycle, stratigraphy, geological time and dating. A useful table correlates the activities to key phrases in the National Curriculum for Science and another section identifies National Curriculum teaching points and offers guidance for teachers.

I know from personal experience just how long it can take to dream up and prepare activities for teaching children, for OU tutorials and for evening classes: "ready-made" material is always welcome. Whilst these books are really aimed at school teaching there are certainly some ideas here that could be adapted, for evening classes in particular, such as the one where a beaker containing a layer of red candle wax, then a layer of sand, and topped up with cold water, is heated over a Bunsen burner to produce a volcanic eruption!

If you teach Earth Sciences, or even if you want to add a little something to your route through the OU courses, at this price the series could be well worth considering. (And I would have said that even if Dr Dee Edwards had not been mentioned in the acknowledgements!)

Linda Fowler BA Hons (Open) and OU Tutor

Geology and Dry Stone Walls

Philip Clark

Geologists and wallers both categorise rocks – but in very different ways.

Geologists want to know how the rocks were formed, what are they made of? So they come up with the igneous-sedimentary-metamorphic categories; they differentiate igneous into intrusive or extrusive; and then intrusive into basaltic-andesitic-rhyolitic, and so on till you reach high-K basaltic andesite or tephriphonolite or wherever you want to go.

Wallers are a bit more pragmatic; they categorise rocks by what can they do, what sort of walls can you build with them?

Wallers work with two categories: single walls and double walls, though there are also hybrid walls and odd walls. You can see all sorts at the National Stone Centre at Wirksworth where, on the first May Bank Holiday this year, the Dry Stone Walling Association built the Millennium Wall Project, with about twenty examples of different types of walls in different rocks from around Britain.

There is a single dyke of welded quartzite from Sutherland with the big boulders stretching right through the wall. Next to this are two odd walls: one of Caithness flags set vertically into the ground (there are similar slate "fences" in North Wales), and a North Wales clawdd, earth filled and stone faced (similar to Cornish "hedges"). A granite single dyke from the South West Scotland branch is partly hybrid – having some of the characteristics of a Galloway dyke, where the bottom courses are double and the top single. If there was a Cornish branch there might have been a wall with stone set vertically or in herringbone fashion. Sometimes one thinks the western fringes of Britain have the oddest geology, and so produce the oddest walls.

Double walls are categorised into coursed, random and random-coursed. Level-bedded gritstone, mostly Carboniferous, was brought for coursed walls by several northern branches from Cheshire to Northumberland and also by the South Wales branch (Blue Pennant). Quartz dolerite from SE Scotland made a random or random-coursed wall. Level-bedded stone is never as level as you think it will be and needs a great deal of hammer work to make it butt up tight and sit straight. Most very irregular stone can be dressed to make at least a random-coursed wall, though with a very hard whinstone (as wallers call various basaltic types) or a very splintery andesitic tuff (Figure 1) it really is not worth it.

Figure 1. Random wall built of andesite tuff, Upper Gilwern, Ordovician Inlier near Builth Wells

These specimen, demonstration walls are of specially assembled various stone types, but where does the stone come from for field walls?

Normally walls are built from local stone if possible – I am talking mainly of field and garden walls. After all, walls began with farmers using fieldstones which they had cleared from the fields, or stone from quarries near walls.

Nowadays wallers may well go further afield, as I did once to a Wenlock turbidite and gritstone quarry NW of Newtown. But the durability of the stone has to be strongly considered; Penstrowed Grits are tough, but the mud-rich, as opposed to sand-rich, turbidites, perhaps because of slumping in formation, proved quite the reverse once they were built into the wall. They exploded in strange shapes and I had to replace some a couple of years later.

Figure 2. Random coursed garden wall of Ludlow and Old Red Sandstone, Llaneglwys, Breconshire.

Similarly, for the walls behind my and my neighbours' houses (Figure 2) it would have been most convenient just to go up the slope behind into the forest, where there are quantities of Silurian stone available. But these are Ludlow beds and very shaly in the sense that the stone continually splits into thinner and thinner laminae – useful as shims to pack behind building stones and level them up, but that is about all. I obtained most of the stone for those walls from an Old Red Sandstone quarry a few miles away, and also found a number of glacial erratics lying around the forest – more tough grits from somewhere further north in Mid Wales. They were a bit rounded by their experiences, but not to the point of being well rounded cobbles which would make them extremely difficult to use in a dry wall.

I had similar problems at Llandeilo Graban Church just across the Wye and the Radnorshire border (Figure 3) still on the Ludlow Beds. As I pulled the old wall down, many of the stones which I was hoping to put back just disintegrated into little blocks, and I was frequently glad I was wearing safety boots. We had to comb the parish for extra stone - some tougher shale was available, but the best, out of old barns, was Silurian sandstone.

So, perforce, some walls are rather mixed in their stone types.

Naturally, you will find more mixtures of stone type when a wall crosses different rock types. The wall pictured in Figure 4 on the

Figure 3. Churchyard wall in Ludlow shales and flags, Llandeilo Graban Church, Radnorshire

Rhinogs is supposed to be the longest continuous wall in Wales, with no break for ten miles, even for a gate. It runs from above Barmouth, over Dyffwys, down to the bwlch in the photograph and up onto Y Llethr, then down and up to Rhinog Fach. As this is the Harlech Dome it crosses repeated bands of Cambrian shale and gritstone and its character constantly changes. A similar, perhaps even more dramatic, change occurs on various walls in the Brecon Beacons National Park, where walls run from Old Red Sandstone to Carboniferous limestone and back.

Figure 4. Field wall of Cambrian grits and slates, Rhinogs, Merioneth.

Of course two contrasting rocks can also be used for show, as in Figure 5; this property front wall, using two contrasting volcanic rocks to great effect, was seen below Vilaflor on last year's OUGS trip to Tenerife.

Let us turn to some construction aspects and consider what the stone shape will do, or not. These are principally, from the geological point of view, to do with bedding planes and with jointing.

Dry wallers have one point in common with geologists: respect for bedding planes. Wet wallers turn stones anyhow, frequently on their sides to make imposing looking "jumpers", because they can make them stick there with mortar. Dry wallers almost always lay stones flat (which is going to make the wall more stable) and in its bedding plane, which also leaves it less prone to unwanted lamination, or exfoliation.

Figure 5. Garden wall of scoria and lava flow blocks, below Vilaflor, Tenerife.

On the other hand many dry wallers have a great temptation to do one thing wet wallers do as a matter of course – to use the best biggest face outwards, like laying a brick, rather than turn the stones into the wall. This is known as trace laying and is a great temptation where there are rectangular stones with good faces on the long sides. Although some of these walls have lasted a long time, their construction cannot be as solid as if the stones are turned inwards. My walls, like the one at Capel-y-ffin Youth Hostel (Figure 6), have nearly always looked as though they were built with smaller stones than in fact they are, because what you see is the cross section!

Figure 6. Mountain wall of Old Red Sandstone, Capel-y-ffin Youth Hostel, Black Mountains.

Building into the wall is especially important with foundations and with retaining walls. Foundations need to support the best part of a ton above them and retaining walls sometimes have to hold back quite a slope.

Some rocks do not form big stones: for example, quite a lot of the Cotswold Jurassic limestone and the South Wales Carboniferous

coal measures. (Incidentally, there is a surprising amount of walling on the farms above the South Wales valleys, where hedges will not grow and no-one sees the walls as there are no through roads.)

This lack of big stones affects not only the kind of foundations that can be laid but also throughstones and copes. A good wall will have regular lines of stones going right through from one side to the other. Gritstone throughs were regularly brought to the Craven district to make up for the lack of them in the limestone. A Cotswold or South Wales wall may be narrower for its height to make up for not having big foundations or regular throughstones. On the New Red Sandstone and some of the softer Coal Measures sandstones, copes were in the past elaborately trimmed to semi-circles or triangles.

An aspect of stones geologists are usually not much concerned with is jointing. The shape of any stone does not much matter to them, but it does to a waller who wants his wall to look good as well as stand firm. How the natural jointing has shaped the stone applies to the rectangular edges mentioned above, and there is another important aspect of the stone to the waller - its face.

Some stone types do not have a face or only if they are dressed rather artificially. Others have been so jointed that a face at right angles to the bedding plane will look good in the wall and give a generally smooth effect to the whole face.

Often the natural face of the stone slopes slightly, usually back from the bottom to the top of the bedding plane, giving a chamfered effect. In Britain where walls are battered this helps the batter; in the United States the stone is often turned upside down because they like straight sided walls and do not want to be insensibly led inwards by this natural batter on the face.

Sometimes the stresses which led to the jointing produce very interesting rhombic shapes – and that can lead to problems. If you place a stone in the wall with a pronounced obtuse angle going in (as you look at it from above), you then have to find a triangular piece or at least one with a corresponding acute angle. Triangles are useful; diamonds are best split in half with a hammer to give two triangles. You do not want to give the impression that walling is a jigsaw puzzle.

It is not, any more than it is a dying art. I hope I have given a few ideas about how geology influences the practice of the craft.

Author
Philip Clark is a retired Dry Stone Waller who is on the Management Committee of the Dry Stone Walling Association, previously as the representative of the South Wales branch, now as International Co-ordinator. His interest in geology sprang from questions concerning the stone he was using.

Book reviews

Oceanography: An Illustrated Guide by, C P Summerhayes and S A Thorpe, 1996 (2nd Impression 1998), Manson Publishing, 352 pages, £24.95 (paperback) ISBN 1874545375.

This book was first published in 1996 and the Second Impression came out in 1998. It was produced to mark the formation of the Southampton Oceanography Centre (SOC) which brought together the NERC's Institute of Oceanographic Sciences and Research Vessel Services with its three ships, Discovery, Charles Darwin and Challenger. All but two of the contributors were based at SOC.

The 22 beautifully illustrated chapters reflect the interdisciplinary nature of the subject, touching on geology, physics, chemistry, biology and meteorology. The opening chapter traces the development of ideas from the early Greek philosophers, through the discoveries and theories of the 17th century, the improvements in navigation and expeditions in the 18th and 19th centuries, including the origins of deep sea exploration, up to the advances made in the 20th century.

It is a book which can be dipped into, to suit individual interests or requirements, rather than read from cover to cover. Even for someone not planning to study Oceanography, there are chapters which will appeal to anyone who has studied geology – The Evolution and Structure of Ocean Basins; Slides, Debris Flows and Turbidity Currents; Mid-Ocean Ridges and Hydrothermal Activity. For those mainly interested in biology there are chapters on Animals in the Deep Sea; Ocean Diversity; Life in Estuaries, Salt Marshes, Lagoons and Coastal Waters; and Light, Colour and Vision in the Ocean which has some stunning photographs. Of general interest are chapters on Artificial Reefs, Scientific Diving, Ocean Resources and Waste Disposal in the Deep Ocean.

Each chapter has clear, well annotated diagrams and an excellent list of References. As well as a good Index there are reference pages on Some Commonly Used Words and Terms, listed under two headings – Depth Zones and Plankton, Bacteria and Marine Animals - and then there is an extremely useful list of Acronyms where you can find the meaning of such letters as GLORIA and MORT (Geological Long Range Inclined Asdic and Mean Ocean Residence Time). At the beginning of the book there is a coloured map of the global oceans, the Geological Time Scale and a page devoted to SI Units. For its informative content and superb photographic reproductions this book is well worth the price.

Elizabeth Maddocks BA (Open)

Coal Resources Map of Britain (1:1 500 000), 1999, BGS, Folded £4.95 ISBN 0751832480

The main map of Britain shows where the major coalfields are situated. Colour coding indicates whether the coals at the surface are Tertiary, Mesozoic or Carboniferous in origin. Three small maps show the known extent of coals on the UK Continental Shelf. The concealed Carboniferous deposits at depth are shown in different colours - the colour changing every 1000 m. These areas are also contoured.

Each major field is enlarged around the edge of the poster and some have generalised vertical sections for their area. The information around the sections is interesting but the typeset is rather small if the poster is to be used by students to extract data.

Jean Sampson BSc Hons (Open)

Geology of the Invermoriston District by F May & A J Highton, 1997, BGS, 77pp, £30.00 (paperback) ISBN 0118845322.

If you are wondering what to buy a geologist for Christmas, birthday or at any other time; if you are visiting or leading a field trip to the Invermoriston district; if you are an armchair geologist or a geology student, then I recommend a copy of the British Geological Survey memoir on the Geology of the Invermoriston district.

This (soft-cover) book provides a detailed description of the geology written in simple, straightforward terms. It is illustrated with a wealth of diagrams, maps, charts, cross-sections and photographs. The authors guide the reader through each period of geological history. There is also a section on geophysics and one on economic geology. There is something for everyone. At £35 it is good value and one of those books you will want to have in your library.

Ron Whitfield

Showcase 2000: Poster Abstracts

An event within the symposium at which members of this Society who have done something remotely geological outside the limits of Open University courses can tell other members of their achievements.

Experimental syn-tectonic dehydration of Serpentinite - a PhD Thesis
Chris Arkwright BA Hons (Open), MSc (Manchester)

Professor Ernie Rutter, my supervisor for the MSc Mam Tor measuring project, was very encouraging when I asked if he would support my application to study part time for a PhD in experimental rock deformation and he suggested I expand on some work he and his wife, Dr Kate Brodie, had already done on serpentinites. In my PhD studies the aim is to devise and carry out experiments to measure the yield point, or strength, of serpentinite under various combinations of porosity and stress at ~500°C and 200MPa, i.e. the conditions for a phase change to olivine by means of dehydration.

Water released during the metamorphism of hydrous minerals, such as serpentinite, can result in excessive pore water pressure which greatly weakens rocks at depth in the Earth's crust. Limited experimental work in this field to date has shown that deep crustal rocks weakened in such a way could result in fault movement at the surface. However, more strength data are urgently needed by modellers investigating this phenomenon. Therefore, these studies could contribute to a greater understanding of such tectonic processes and thus help to mitigate the catastrophic effects that major Earth movement (eg the San Andreas Fault) have on populations worldwide.

My PhD studies are partly self-funded with some help from the Crowther Fund, which was established to assist Open University graduates in postgraduate research or further study leading to a change of career. My post graduate studies have already led to a new career in teaching as a tutor on the new OU S260 Geology course and on geology courses at Manchester University's Centre for Continuing Education, both of which I enjoy immensely.

Authigenic minerals - a different perspective
Jane Clarke

Fossil bone provides a sheltered micro-environment in which authigenic minerals can precipitate from percolating groundwater. The order and nature of the authigenic mineralization can be used to infer the physio-chemical conditions at various stages of diagenesis. The precipitation of minerals in the bone cavities depends upon the composition and rate of flow of pore-water, the local concentration of ions and the local Eh and pH values. This information can be used to reconstruct diagenetic pathways for the bones and thus provide a window into the diagenesis of the surrounding strata. Compiled from "The diagenesis of Lower Cretaceous vertebrate fossils from the Purbeck Formation of Durlston Bay, Dorset, and the Wealden Group of the Isle of Wight" by J B Clarke, Unpublished MPhil Thesis (Open) 1993

After completing my BA Hons (Open) in earth sciences and physics, I went on to complete a MPhil. During the diagenesis research I became interested in the histology (micro-structure) of the bones and directed my research in that direction. I am currently an Honorary Associate at the University of Portsmouth, working with an international team on the histology of vertebrate fossils. I have given talks on histology and / or diagenesis, both in this country and on the continent and have published several papers. I have been OUGS Journal Editor since 1991 and thoroughly enjoy producing the interesting papers constantly submitted for publication.

Sir Charles Lyell (1797-1875) the Hampshire / Oxford connection
Paul Clasby

The Project: In 1973 the Oxford University Museum[1] (as it then was) asked me to assist with its Tertiary fossil collections; I am now an Honorary Associate Curator of the O.U.M. of Natural History (as it recently became). When the initial work on Barton fossils was (largely) finished, the next job was "just clean and tidy the LyelI Collection of Tertiary Fossils", 100+ drawers[2] of specimens in a state of some neglect - but, bearing in mind that Lyell based his divisions of the Tertiary into Eocene, Miocene and Pliocene on the fossil content, this was important historical material. Over many years, in holidays until I retired, the fossils were partially cleaned, mostly reunited with original labels, recorded in a two-volume manuscript catalogue and a 16,000+ entries database. I learned that Lyell had once been a Hampshire schoolboy, brought up 11 miles from Lymington at what is now the Bartley Lodge Country House Hotel[3] (*c*.90% of professional geologists were/are not aware either). I persuaded the hotel management to install a commemorative plaque[4] and they use as 'complimentaries' offprints of my article[5] for a local history magazine about Lyell's Hampshire connections; I was also involved in a commemorative symposium at Exeter College, Oxford (Lyell's college) and the International Bi-Centenary Lyell/Hutton Conference in 1997- which included a lunch at the Hotel and my first lecture to a professional audience (fortunately just 10 minutes on the terrace!).

Current Activities - My work at Oxford continues, now on the generality of their Tertiary material. I tutor Earth Sciences locally for The University of The Third Age and am a national informal advisor on General Science. There are many Barton field trips to lead, and I retain an interest in the OU through the 'Fossils' element of the OUGS London Revision Day for S260. At Bournemouth University I am involved in promoting Public Awareness of Science and am a more or less active member of several national scientific societies, including the Geological Society, Geologists' Association, Palaeontological Association, Geological Curator's Group, History of Geology Group, Tertiary Research Group, Dinosaur Society, British Astronomical Association, the British Association for the Advancement of Science (Wessex Committee member), the Royal Institution and an extensive number of locally based geological, astronomical and history societies.

Material displayed:

[1]Photograph of Oxford University Museum

[2]Photograph of the contents of two drawers

[3]Photograph of the Hotel - south front; plan of hotel showing the

original house of 1759 and the extensions made by Lyell's father in 1811; Photograph of 'The Crystal Restaurant', once the library of 1811, where the young Lyell read many significant natural history books, particularly *Introduction to Geology* (2nd edition 1815) by Robert Bakewell who accepted James Hutton's ideas about the age of the Earth.

[4]Photograph of commemorative plaque

[5]Copy of article *Bartley Lodge & Sir Charles Lyell - the Geologist's New Forest Boyhood* reprinted from *The Hatcher Review*, 1997, as an illustrated souvenir booklet.

Edhen Vean - kite aerial photography
John & Sandy Colby

A birds eye view is all very well if you have wings, and few humans possess this attribute. So in order to gain some sort of aerial view of ground structures, you have to get some sort of viewing device in the air. Using powered aircraft, full size or model, is costly and has penalties regarding transport - they are heavy. Using kites for taking photographs has been around for nearly a century, but this was a project designed round the availability of someone without workshop facilities and using only hand tools to construct a flyable means of taking aerial photographs activated by radio control. The design principles specify that it has to be able to be carried in a rucksack so that it can be used in the course of normal fieldwork. The method of construction was chosen because what can be built by hand would also be easy enough to mend by hand in a tent when the whole thing crashes to the ground. So Edhen Vean (little bird in Cornish) was born and has flown across a variety of terrains taking photographs of a variety of subjects. We were aided in this by a bursary in 1998 from the Ian Gass fund and currently the designs are being modified to increase facilities and usability.

Mapping minerals from historical records
John & Sandy Colby

This started with a data book of mineral production from mines in Cornwall and Devon. It had loads of statistics but did not have a map. What it did have, however, was an OS grid reference against each mine, and what we had was a suite of office programs which included a database and spreadsheet, this latter allowed the plotting of graphs.

A map is an X-Y graph. - so taking the data into a database and then into a spreadsheet was quite a simple task, if requiring some typing. Then by plotting the resulting data onto a graph and adjusting the axes to print out as a square grid, a map is produced which could be related to a topographic or geologic base map by printing out at the correct scale onto OHP foils and overlaying them onto printed maps. This scaling is a matter of trial and error and adjustment until the scale is correct for the base map in use. What is achieved is a low cost mapping tool that virtually anyone with a PC and standard software can achieve from whatever original data if it can be expressed as a map. The method is not sophisticated but has the advantage of being available to virtually everyone with a computer of whatever type with widely available tools. The technique has been used in the TLTP project on Resources.

Specifically for Devon and Cornwall, we found what was expected. The spread of the type of mineralisation in the hydrothermal system was exactly as predicted: tin closest to the granite, then copper, lead/zinc and iron. What could then be seen was, by selecting the data differently, the production of mines, the richest mineral areas and other granular detail which was not obvious by scans of lists of figures. The technique is superseded by a multitude of packages and applications both for ease of use and sophistication, but for basic analysis and low cost it has proved invaluable.

Both John and Sandy have BA (Hons) degrees from the OU, Sandy additionally has gained her BSc. She is currently pursuing an MA in Cornish Studies with the University of Exeter. John is collating historical records for the book which is scheduled for publication in 2001 or 2002.
Website at http://www.colbybos.demon.co.uk.

The geology of Languedoc
Brian Dawson

The display demonstrates the wide range of the geology to be found in the Languedoc. The exhibition boards show a number of photographs of geological features, volcanics, minerals, karst and reef structures etc., together with some geological maps and sections showing the complex structure of the Montagne Noire. Also on display are a few specimens of the fossils and minerals present, geological maps and books, my translations of a few of the itineraries from the Regional guide and detailed articles on the classic area of the Montagne Noire.

The geology of the area consists of the very complex Montagne Noire to the north, formed during the Hercynian orogeny, with its metamorphic axial zone and several aggregated blocks of Precambrian to Carboniferous age forming the northern and southern slopes. The north-west is mainly sedimentary sequences from the Carboniferous to Cretaceous. The coastal plain consists of largely Eocene and Miocene sediments, with a chain of volcanics running roughly north-south from the sea into the mountains. To the south-east the hills of the Corbières are generally of Cretaceous age resulting from the Pyrenean orogeny.

On a personal note I have lived in the Languedoc area of southern France for about four and a half years and kept myself occupied studying the local geology, including joining two local geology societies, enjoying the climate and, of course, the food and wine.

A brief review of the geology of the northeastern States of America
Gladys Dinnacombe

I have always been interested in geology and after taking my degree I continued my interest wherever I happened to be at the time. Recent visits to the north-eastern States of the USA have enabled me to look at other geological areas outside the UK, especially New York State, Pennsylvania and Maryland. The geology here is much different from that of the well known areas such as the Grand Canyon which most visitors to the USA generally visit. As my visits are also social visits, I have been able to see lesser known geological sites in the Appalachian area in the above named States. Many State Parks in the USA have considerable geological exposures as well as an interesting history. Visits to Letchworth State Park, Rock City Park and Niagara Falls have provided not only spectacular scenery but also spectacular geology. These north-eastern states of the USA provide a varied geological experience from Precambrian upwards, including

metamorphic, sedimentary and structural geology. Research has not been easy as I always seem to stay well away from any kind of bookstore and have to rely on my own interpretation of the rocks! However, the internet has proved invaluable although much of what is available is out-dated where stratigraphic naming is concerned. Further research in these areas will be undertaken on my next visit. I have a web page which has reports of my previous work in North Wales:
http://www.cerianwen.demon. co.uk/geol.htm

Ground Resistivity and Archaeological remains
Richard & Angela Knisely-Marpole

An Overview of Geophysical Techniques

Those who are regular viewers of "Time Team" will be familiar with the geophysics team and the prospecting work they do. For those who are not so familiar, a brief explanation:

Geophysics can be used to try to locate buried archaeological remains without the destruction of excavation and is frequently used to locate likely sites where excavation can take place.

There are three main methods: resistivity, magnetometry and ground-penetrating radar (GPR). The first two have been successfully used for many years; the last is a relatively new technique.

Resistivity is the main subject of this exhibition, but a brief resume of the other two techniques is given for completeness.

Magnetometry measures changes in the planet's magnetic field. As these changes are small, then the instruments used to measure them must be extremely sensitive. The main problem is that large metallic objects (vehicles on a nearby road for instance) can cause interference, so can external magnetic fields caused by such things as power lines. Even the steel toecaps on a safety boot worn by the operator can render a survey useless (as has been discovered on more than one occasion!). Magnetometry is ideal for locating such archaeological remains as kilns or hearths where the intense heat has permanently reorganised the magnetic field of the heated materials.

Ground penetrating radar has undergone immense improvements in the past few years, with the size of the equipment needed being reduced to a reasonably portable unit. It is best used to locate areas of compressed material such as floors, or voids such as tunnels. I expect GPR to make great leaps forward in the near future, to become a much more useful tool. Hopefully, the cost will also come down to a level where more surveyors will be able to afford the equipment.

Resistivity is a widely used and relatively inexpensive means of sub-surface prospecting. At its simplest, the ground is swamped with a low voltage electrical current and the resistance to this current between two mobile probes is measured.

Generally, resistance will depend on the amount of moisture in the substrate. A buried wall, for instance, will show a high resistance because the stones will be drier than the surrounding soil, whereas an old ditch, filled in with organic matter over the centuries, will hold more moisture and will show as an area of low resistance. Things are never that simple in practice however, and what the surveyor will be looking for is the shape of "anomalies" in the survey plot.

The main drawback with resistivity is the lack of depth. On average, the penetration is half the width of the mobile probes, so for a pair of probes one metre apart, archaeology will only be found to a maximum of half a metre. There is a limit to the width of the probes for practical reasons of portability. Another problem with resistivity is the lack of sensitivity in extremes of soil humidity. Ideal conditions are to be found when the soil is just drying out after a wet spell, but if the ground is waterlogged or parched then results can be disappointing.

The Display

On the display were a number of examples of resistivity surveys used to locate archaeological remains.

The site of a previously unknown turf maze at Llwydiarth in Mid-Wales was demonstrated by a copy of the original aerial photograph from which the maze was first spotted and the plot of the subsequent resistivity survey which was carried out to obtain more detail. Corners of the maze could clearly be seen on the plot.

The resistivity survey across a Roman road, again in Mid-Wales, showed how such surveys are sometimes just a small part of a much larger research project. In this case the author’s mentor, the late Prof. Barri Jones of Manchester University, had requested the survey prior to carrying out an excavation of the road and a suspected signal station adjacent to it - which in fact turned out to be a prehistoric burial cairn. Barri had been tracing the route of this road for many years and this particular stretch resolved the problem of the ultimate destination of the road. This part of the display was included as the author’s tribute to the work of Barri Jones who died in July 1999.

The final part of the display demonstrated the real worth of geophysical survey. Here, an aerial photograph showed crop marks detailing obvious earthworks, except in two areas which were spring-fed and therefore resistant to parching. Resistivity was used to try and fill in the gaps. At the time of the Symposium only the lower area had been surveyed, but the results were impressive. By overlaying the resistivity plot onto a vertical aerial photograph, the earthworks could clearly be seen continuing into the blank area. Also visible in the res plot is a series of lines which have been interpreted as a possible tripartite gateway.

Richard, formerly a qualified Dispensing Optician, decided on a career change and studied at Manchester University for a single honours degree in archaeology, but after two years was seduced by surveying and transferred to Sheffield where he took their excellent Optical & Geophysical Surveying course. He has carried out geophysical and topographical surveys at various sites throughout the UK and in Ireland, including a building survey of Tabley Old Hall in Cheshire for Manchester University which owns this listed building.

Because of the large quantities of data generated during geophysical surveys, Richard has written a program for the Psion Series 3 hand held computer which allows the readouts from geophysics units without a datalogger to be recorded onto a database, which automatically inputs the line and point positions, allowing faster working. This data can then be downloaded to a PC with a graphical interpreter to display the results of the survey.

Richard is also a skilled photographer - using medium format, 35mm and digital equipment - specialising in wild flowers as well as archaeology. Angela, a Superintendent Physiotherapist in North Staffordshire, has recently gained a BSc with the Open University, mainly in Earth Sciences, and is now studying Ecology for her Honours. She is a valuable assistant when sur-

veying, doing much of the running around! Recent work includes assisting the late Professor Barri Jones with surveying portions of a Roman Road in one of the most remote areas of mid Wales and a geophysical survey of two defended enclosure sites near Aberystwyth for a MPhil student.

Art & Geology
Beth Peart

I began drawing and painting long before I'd ever heard of geology, but once I began to look at the world through a geologist's eyes, much in my landscape paintings "fell into place" as it were. My main love has always been watercolour, but in recent years I have also been studying the techniques and philosophy of Chinese Brush painting, and most of the paintings that I have brought to the Symposium are done in this style. The aim of Chinese Brush painting is to capture the essence of a subject, its "Chi" or spirit, rather than to make an exact rendition of one particular example, and so this series of Volcano paintings is therefore an amalgamation of what I perceive to be their spirit….

The materials I use include the traditional "Four Treasures" of Chinese Brush painting:

Inkstone - made most often from slate, which provides a smooth, non-porous finely textured surface on which to grind the ink. Antique ink stones are very expensive, and are considered to be *objets d'art*. Some of the most famous come from Mount Fuke in the Guangdong province of southern China.

Ink Stick - made from compressed pine soot and resins, often beautifully decorated.

Brushes - made with bamboo handles and bristles of various kinds, including rabbit, goat, sheep and horse hair, which have lovely descriptive names such as "plum blossom" and "orchid and bamboo".

Paper - hand made, usually unsized, "grass" or "rice" papers such as Xuan and Mao Bian.

By grinding the ink stick with a little water on the inkstone, a beautiful glossy black ink is produced. I use various types of watercolour, both regular "Western" paints, and Chinese and Japanese pigments in traditional hues - many of them derived from natural inorganic substances such as green from copper, and blue from cobalt minerals. My display includes examples of the "Four Treasures", and I hope that everyone will enjoy examining them, as well as looking at the finished works.

Biography of Ian Gass
Jane Randle

Ian Gass was the founding Professor of Earth Sciences at the Open University who, together with Chris Wilson, put together the Geological component of the Science Foundation Course, S100, in 1971. Subsequently, he shaped many of the Geology courses we have all enjoyed so much. As the first President of the Society, he was instrumental in setting up the Annual Symposium (or Conference as it was in those days) at Reading, to which he invited many of the authors of Understanding the Earth. This Reader for S100 was one of the most successful Earth Science textbooks ever published. He was always hugely supportive of any OUGS activity and very proud of its success.

Within a few years, from an initial staff of two, Ian had built up one of the most successful departments in the Open University, internationally renowned for both research and teaching. Yet Ian Gass did much more, as I have discovered during the past five years, interviewing nearly 150 people, and reading reports and combing the OU Departmental files. Ian was an intensely busy man. He frequently ran two or three projects simultaneously - each one more than enough to keep most other people stretched.

How he achieved this is an important message to share, so the book will include: Ian's childhood and education; his various posts both in education and industry, as leader of overseas projects; and his place on the international scene.

Ian Gass got things done, he was a man of vision and energy who inspired others to give their best. He was enduringly ambitious for Earth Science.

Jane Randle, the OUGS National Newsletter editor, is well qualified to write this book as she was Ian Gass' last research student. She began her studies at the OU in 1971 and joined OUGS as soon as it was formed, having been introduced to field work by Chris Wilson before she started to study S232 in 1973. Jane has been associated with the Department of Earth Sciences ever since. The poster was designed by John Taylor, Cartographer in the OU Earth Science Department, who greatly admired Ian.

High resolution analysis of trace elements in corals by laser ablation ICP-MS to assess the impact of anthropogenic pollution and environmental change in Barbados, W.I.
Lesley A. Runnalls

Coral reefs and their associated communities are affected by environmental parameters such as water temperature, depth and light intensity. The reef environment is also disturbed by human influences such as anthropogenic pollutants which in Barbados are released close to the reefs. Laser Ablation Inductively-Coupled Plasma Mass Spectrometry (LA-ICP-MS) has been used to assess the effects of pollution on the corals and their associated communities. It offers the possibility of evaluating the relative impact of both anthropogenic pollutants and natural stresses. Sclerochronology is also being employed primarily to document the framework and skeletal growth of a suite of *Montastrea annularis* coral cores. X-radiography has shown the annual growth band patterns of the corals which extend back over several decades. Preliminary results using LA-ICP-MS have shown a contrast in the concentration of the trace elements (Mn, Zn, and Pb) within the corals at different locations. Thus this method is shown to be a powerful tool for extracting high resolution environmental records from corals and, in combination with sclerochronology, of showing the relationship between growth rate and environmental pollution.

This study is part of a PhD at the Research Institute for Sedimentology, University of Reading, and follows a BA Hons (Open) and an MSc (Reading). Lesley flies as cabin crew for BA and, through her travels, has become aware of the pollution problems that are affecting many of the islands of the West Indies today.

Yew trees and the land
Penny Stanford

The great yew at Tandridge sparked my interest in the relationship between trees, people, and the land. It had enabled the establishment of the age of yews as thousands of years, since the

Saxon builders of the church had had to accommodate its roots in the construction of the crypt. The dating remains contentious, as does the positioning, since some hold that churches were built where the yews already existed, while others believe yews were planted near the building. There has been little work on the overall distribution, but the dominant influence is the geology beneath, as yews favour Devonian sandstones and the Upper Cretaceous, rather than the climate or people who venerated them as once suggested. A boundary which seemed to indicate that the Danelaw had eradicated older trees emerged as showing that the trees do not grow on boulder clay, which roughly outlines the treaty border; this raises questions about Saxon knowledge of land types. There are differences between the distributions of wild and churchyard yews which are probably more historical (many wild trees in the Lake District and the Peak District are not accompanied by many ancient trees), and the existence of ancient trees outside the area of wild distribution would seem to indicate planting. So would the frequent placement of trees and churches on eminences, which in the Weald and Gloucestershire can be shown to be natural outcrops of local rock rather than built mounds. Sometimes the trees are associated with springs. The distribution at the local level is thus not random, but, once more, dictated by local geology.

World geology in the High Street
Glynis Sanderson

Building materials reflect the geology of the area and man will use whatever is available to him to create his buildings. The High Street offers an ideal location to stimulate interest in geology, where architects, town planners and civic dignitaries, both past and present, have strived to enrich their built environment with an enormous variety of colours and textures through different building materials. This variety can be harnessed as an educational tool in the form of a trail which can provide an interesting method of stimulating interest in geology.

Whilst *in situ* geology is the best way to understand and recreate the past history of a rock and its environment, it is often limited to a single rock type at a single location. The urban environment complements the primary one by having a wider variety of rock types available at a single location. It also has the advantage of being easily accessible.

With education in mind, a database of urban geological trails was created in the hope that it can be continually updated and made available for all to use. A history of urban geology and geological trails was written. Many trails were studied to look at the way the geological information was presented to ascertain whether there was a better way to write a trail. The wider aspects of urban geology and street furniture were also studied as these items were often good sources of geological material not included within a trail. Topics covered include churches, cathedrals, churchyards, cemeteries, fountains, walls, pavements and kerbstones.

This work formed part of my MSc thesis awarded in 1999. Having previously completed a BSc (Hons) studying Earth Sciences with the Open University, I was in the happy position to be able to combine my interest in geology with my professional qualification in Information Studies.

Down to Dorchester - A Millennium project
Doreen Smith

A photographic record of the watershed of the River Frome in Dorset. The full Project title is 'Down to Dorchester: The Geological Journey of the Frome from Benville to Bradford Peverell'. The Down has a double meaning as the river flows down to the sea via Dorchester but starts its journey on the Chalk Downs which surround the project area. The aim of the Project is to link the familiar everyday countryside to the geological history of the area. I have looked at roads, bridges, fords, building stones, ancient industries (such as brick yards, tanneries, corn mills) water meadows, Roman villas and aqueducts, mediaeval and modern fishponds, watercress beds, nature reserves and ancient fields. I have also looked at ancient and modern maps. I have booked village halls throughout the area covered by the Project and taken the displays to Village Fetes, Christmas Fairs etc. I am also giving talks from one end of Dorset to the other as so many people have become interested. I have produced a colourful leaflet which has been distributed to every household in the area of the Project with the basic information and an Information Board for Frampton Village Hall which is where the whole idea began.

The display consists of some of the photographs, a full size copy of the Information Board, reference books, maps (geological and road) and fossils/rocks of the area. There is an account how the whole thing grew from a very small idea to start with. I applied for a Millennium Award under the Help the Aged Award Scheme and was successful to the tune of £2000.

Dorset RIGS (DIGS)
Doreen Smith

The Display is a visual record of 60/70 RIGS which, along with local rocks and fossils, is used at public events throughout Dorset. There are rocks on display, plus leaflets and trail guides that we have produced. Most of the posters are in A3 folders purchased for the purpose but there is also material on display panels which I have been loaned by Stalbridge Linen Ltd. which is sponsoring this Display.

Dorset has been working on RIGS projects for some six years now. The first object was to register and define geological sites throughout the county on the basis of landowner co-operation, accessibility, safety and, of course, geological interest preferably educational. DIGS is now in the process of adding geomorphological sites to the portfolio, again throughout the County. DIGS is working at providing information boards, leaflets, trails and any other way of getting the availablity of these sites across to schools, geological parties and the general public.

DIGS is also monitoring the sites, maintaining the sites and improving the sites where possible. The funding for all this comes from a variety of sources: various District Councils, English Nature, Dorset Wildlife Trust, RSNC, Dorset GA Group and private individuals.

My interest in Dorset Geology grew through doing S100 and then S236 and all the other geology courses from thereon. It is a wonderful excuse for trolling round a fascinating part of the English countryside, dog at heel, camera at the ready. There is always something of interest round the next corner, over the next hill. Hopefully I will still be doing something geological in Dorset for a few years yet.

Book reviews

The role of the Sun in Climate Change by D V Hoyt & K H Schatten, 1997, Oxford University Press, 279pp, £25 (paperback) ISBN 019509414X.

It is always easier to write about a subject that one has some understanding about. This reviewer has a great interest in solar activity, often observing sunspots and other solar phenomena. Then there is the view long held, that perhaps man may not be responsible for much of the "global warming" of which "we" are accused.

Since life first appeared on Earth, the Sun has been important in sustaining it, for without its heat and light, Earth would be a frigid mass. Dire predictions are made almost hourly regarding increased $C0_2$ emissions. Yet it transpires that the "soothsayers" may actually have it wrong.

In the 1930's, Denver in Colorado experienced record cold levels, since when the climate has progressively got warmer. This example has been cited many times as "proving that the climate is getting warmer". Research later proved that the thermometer had been moved from one room to another and from one floor of a building to a higher floor!

Hoyt and Schatten claim that the climatologists are ignoring specific information to make the results fit the model they are using, and refusing to account for solar influences by claiming that the Sun has a constant output in light and heat and therefore it does not matter, even when evidence from various sources is presented showing that the solar constant is anything but constant!

Several authors have claimed that the influence of the Sun over our climate is greater than has been previously suspected. The authors show that the sun has a series of cycles of varying length - the sunspot cycle of about 11 years is one cycle; but there are others. It is claimed that these cycles account for much of the proclaimed global warming. The geological and historical records retain information regarding solar influences. Indeed there is the recorded Maunder Minimum when solar sunspot activity was non-existent for several decades. The "mini ice age" occurred during this time. Coincidence? Hoyt and Schatten think not.

This book seeks to put "Man's influence on Global Warming" into perspective. If the sun is indeed getting hotter then, regardless of what man does or does not do, it is inevitable that the ice caps will melt, sea levels will rise in real terms, the climate will get warmer and species will die out.

The "Greener than thou" will not like this book because it places much of the evidence for environmental changes on a purely scientific basis, not on some hysterical "We're doomed" scenario. Mankind has got to re-evaluate the way we live and use the resources of the Earth. However, it must be realised that the Earth's environment is as much a continuum as is the Sun. To stop the evolution of the environment will require a catastrophe and, if the Sun provides it, whilst we may not like it, it will be the great Amen.

I enjoyed reading this book and commend it to all who have an open mind about "global warming", many questions do remain unanswered.

Gerard Vallely continuing Earth Science student

A Colour Atlas of Carbonate Sediments and Rocks under the Microscope by A E Adams & W S MacKenzie, 1998, Manson publishing Ltd, 180pp, £24.95 (paperback) ISBN 1874545847.

What can I say? A really splendid book! If you are already familiar with the format of previous publications in this format, *Atlas of Rock Forming Minerals, Atlas of Igneous Rocks and their Textures, A colour Atlas of Rocks* and *Minerals in Thin Section*, then you will need no introduction, suffice for me to say that this book is of the same high standard.

The quality of the 300+ photographs, crucial to this type of work, is extremely high. The book can most certainly be used as the authors intend, "as a laboratory manual … and as an aid to identifying grain types and textures in carbonates".

Even outside of its technical/academic role it is a book that gives great pleasure to casual browsers. Even if you hate sediments (I love them!) you cannot fail to marvel at the diversity of textures and bioclasts illustrated within its pages!

As well as a brief explanation of limestone classification using the Folk and Dunham Schemes, there is also a short chapter on Cathodoluminescence with some beautiful thin sections used to illustrate this complimentary branch of carbonate petrography.

Over 50 pages and 100 thin sections are devoted to diagenesis of carbonate rocks, a reflection of their susceptibility to and importance of this process. This naturally leads onto a short chapter discussing porosity of carbonate sediments, of vital importance to those seeking hydrocarbon reservoirs!

So to summarise, this is a book that should grace any true geologist's work bench or lounge coffee table. It is with great reluctance that I return this copy to OUGS – I will have to buy a copy now!

Allan Hale, Continuing ES student

Geology of the country around Trevose Head and Camelford, by E B Selwood, E M Durrance & C M Bristow, 1998, British Geological Survey, 106pp, £32.50 (paperback) ISBN 0118845144.

I confess that I borrowed this description of the geology of a fascinating area to review because I'm too mean to fork out £32.50 to buy it! This type of publication has shot up in price over recent years to the point where I, together with most of my acquaintances, unfortunately cannot afford to buy them but have to rely on libraries.

This is the 2nd edition of a memoir originally published in 1910, and a complete re-write. The sheet memoir follows the familiar pattern, including accounts of all the geological formations in the district, the granite and the resources of the extractive industry. It draws on results of recent mapping and research in an area which has now been substantially re-interpreted, starting with the development of the Devonian Trevone Basin and following its history through the Carboniferous Period into the Variscan Orogeny and the associated hydrothermal episodes which resulted in mineralisation and kaolinisation. This is all illustrated with clear black and white photographs.

A major section deals with the complicated structural history, and recent revisions to the stratigraphy, of the four units that comprise the area. I particularly liked the detailed field sketches of structural evidence. It is useful that some grid references have been included but it does seem a great pity that these are so few in number: only a selection compared with the exhaustive lists of earlier sheet memoirs. Interpretative line drawings are another useful aid to understanding the detail of the structure. The book concludes with a look at the minimal Quaternary history of the area, and a section on the economic geology.

However, this detailed and well produced description remains an essential work of reference for anyone studying the geology of this popular Area of Outstanding Natural Beauty, and is certainly going on my 'wish list' for next birthday!

Linda Fowler BA Hons (Open) and OU Tutor

Geology of the country around Derrygonnelly and Marble Arch. Memoir of the Geological Survey of Northern Ireland, Sheet 44, 56 and 43 (Northern Ireland) by I C Legg, T P Johnston, W I Mitchell and R A Smith, 1998, 82pp, £12 (paperback) ISBN 0118845314.

One of a series from the Geological Survey of Northem Ireland (GSNI), this memoir covers the area between Lower Lough Erne in County Fermanagh and the borders of Counties Leitrim and Cavan in the Republic of Ireland.

The account is the culmination of previous research with a resurvey of the area. It includes a revision of the stratigraphy, clearly illustrated in table form, allowing comparison with the nomenclature of the past. Recent seismic reflection surveys and information obtained from the drilling of deep boreholes provides the basis for a reappraisal of the

structure of the area and an interesting up-to-date account of the state of hydrocarbon exploration in this part of Northern Ireland. The extensive secondary dolomitisation found during the course of this survey is also of economic interest.

The oldest exposed sedimentary rocks are mudstones and sandstones of Devonian age. Borehole data confirms an underlying metamorphic basement, thought to be of Moinian age. The Tyrone Group and Leitrim Group represent the Carboniferous; the former being made up mainly of limestones and shales, the latter comprising shaly mudstones with subordinate sandstones.

The top Formation of the Tyrone Group is the Dartry Limestone. This formation consists mostly of bedded limestone with shale partings which is exposed at the Marble Arch caves. Reading this part of the book brought back fond memories of caving in the area. The same cave system has now been opened up as a tourist attraction and is accessible to many more people. Wet suits are no longer required!

Several major dykes and sills intrude the Carboniferous and older strata. The dykes form part of the Donegal-Kingscourt swarm.

While the overall presentation is clear, colour photographs of the area compensate a limited range of colours used in the diagrams. The real strength of this memoir however is its ability to provide a general and readable overview of the rock formations alongside detailed geological accounts of grid referenced locations. Such a comprehensive guide is best read in bite-sized chunks.

Jenny McKinley BSc Hons, PGCE, former OU tutor and continuing PhD student of heterogeneity of sandstone properties.

The Crucible of Creation: The Burgess Shale and the Rise of Animals by S Conway Morris, 1998, Oxford University Press, 242pp, £8.99 (paperback) ISBN 0192862022.

This book is a direct attack on the ideas presented in *Wonderful Life* by Stephen Gould, but as I have not read the latter, the arguments were somewhat lost on me. Simon Conway Morris made his name in the study and interpretation of the fossils of the Burgess Shale and theories regarding the so-called “Cambrian Explosion”. Stephen Gould has a different interpretation and Conway Morris has set out to refute Gould’s theories and to prove his own.

After an overview of the structure of life and the oldest known animals, the Ediacaran fauna, the finding of the Burgess Shale deposits by Charles Walcott is related together with an account of the subsequent transportation of vast amounts of material to the Smithsonian Institute in Washington, where it was examined, described and interpreted.

We are then taken on a wonderful trip in a submersible time-machine back to the Cambrian and life on the sea floor during the sedimentation of the Burgess Shale. Each animal, with reference to its fossil, is described in detail as it goes about its business, its colouring, movements, feeding habits - Conway Morris has a great imagination. His chatty style and vivid commentary conjours up a world of arthropods, sponges, polychaets and many more; one feels a sense of sadness when the submersible returns to the surface and to the present.

Conway Morris then turns his attenton to relationships between the various animals and presents some (but not many) cladograms. Plausible connections and evolutionary trends, many convergent, are discussed in detail, each with reference to the particular fossil.

Gould’s view was that there was maximum diversity in the Cambrian which has decreased ever since; Conway Morris argues that, on the contrary, the Cambrian explosion reflects the present day diversity and that evolution has progressed in a series of leaps and bounds resulting in the wide number of current species. He concludes, rather smugly, that, “Steve Gould’s claim that the disparity of Cambrian arthropods was substantially greater appears to have been neatly refuted”.

The book is written in a chatty style and is easy to read; the ideas are clear and concise and reasonably easy to follow. Constructive criticism is always welcome, but I found it a little petty in places. However, I shall re-read the trip on the submersible time-machine over and over again.

Jane Clarke MPhil (Open)

Time Machines by Peter D Ward, 1998, Copernicus, 260pp, £14.95 (hardback), ISBN 038798416X.

This is not a reference book, but tells a story, the story of how "Time Machines" enable the geologist to unravel the history of the Earth and its inhabitants from the fossil and stratigraphic record. The book has a secondary title, "Scientific Explorations in Deep Time", which could equally be put as "Cautionary Essays on the Scientific Method", because this is in essence what the book comprises.

So what is a Time Machine? Certainly not yet the contraption portrayed by H G Wells in his classic novel. As the author states in the preface, it can be any scientific tool, technique or philosophy that helps in building up a better picture of the past whether it be a mass spectroscope, a hammer, field notebook and pencil, or a thought experiment.

The book itself is divided into four main sections, entitled "Finding Time", "Place", "Inhabitants" and "The Time Machine" the last being a summary written in the Wellsian style. The first section looks at the fossil record and how radiometric and magnetic clocks have been developed to place fossils in an absolute time frame. It highlights the difficulties in achieving this and the pitfalls and frustrations of working in the field and the laboratory. The second section touches on environments, sea-level change, continental drift and plate accretion. It is in this section that I had some difficulty in following the thread of the author's argument, as he seemingly went off at tangents. I found the third section the most entertaining, littered as it was with tales of how unsubstantiated hypotheses have been (and probably still are) held up as self-evident truths, sometimes for generations, before being debunked by advances in scientific methodology.

The overall approach is autobiographical in that the author describes episodes from his career to elaborate on the theme that, although a single piece of evidence from the past might not tell us much, the proper interpretation of an accumulation of scientifically tested hypotheses can yield a fascinating picture. The description of some techniques is superficial, but there are textbooks to refer to for this. There is not a single reference in the text to the 20 or so diagrams included, which appear to have been added as a late afterthought.

So, to whom is the book directed? The author claims it is one of those "books written, in other than a textbook format, for people who love science". Written by an American for an American audience, its message is nonetheless global. A student of S260 or S269 would find it a thought-provoking supplement to the course material as it deals with the real world of practical geology. It is well worth the modest investment to include it in a scientific library.

Roger Baker BSc Hons (Open)

Geological Maps – An Introduction 2nd edition by A Maltman, 1998, John Wiley & Sons, 260pp, £19.99 (paperback) ISBN 0471976962.

My study of the interpretation and use of geological maps had been limited to Block 1 of S236 in 1983, so reading this book was almost like starting again from the beginning.

Like Block 1, it is aimed at the novice, and starts from the basics: definitions and concepts which, if not grasped early on, can lead to confusion, such as the difference between large-scale (small area) and small scale (large area) maps. As well as introducing basic terms and concepts, such as strike and dip, folds, faults and unconformities, he shows how 3D fence and block diagrams can be developed.

The structure of the book will be familiar to OU students with chapters concluding with a summary and, where appropriate, exercises to complete. I particularly liked the fact that these exercises are based on maps from a variety of countries and not just the UK: he uses examples from France, Canada, Australia, New Zealand, South Africa and the USA, thereby introducing various formats and terminologies of international map-making.

Further chapters cover the usage of geological maps in environmental geology: by planners when assessing the extent of economic deposits, the impact of extraction of mineral resources or the likelihood of pollution of groundwater and problems from waste disposal. He advises on how botany, building materials, even place names, can give an indication of the underlying geology or the extent of various formations.

I found the final chapters covering a brief history of geological map-making and map makers particularly interesting. Whilst in the 17th and 18th centuries attempts had been made, in France and Russia, as well as in the UK, to depict soils and rocks at the Earth's surface on maps, it was William Smith with his famous map of 1815 who grasped the sequential arrangement of sedimentary rocks. Other geological maps soon appeared in various other countries as well as here and, although initially these were the work of individuals or learned societies, gradually governments became interested as they realised the importance of geological surveying in bringing territory under bureaucratic control. The problems of illustrating geological data on often inadequate topographical base maps and then reproducing them are also described

Alex Maltman's book is both a useful manual for the beginner and an interesting history of map-makers and map-making.

Hilary Tatton BA Hons (Open)

An Introduction to Optical Dating: The Dating of Quaternary Sediments by the Use of Photon-stimulated Luminescence by M J Aitken, 1998, Oxford University Press, 267pp, £75.00 (hardback) ISBN 08540922.

They say that you should never judge a book by its cover; well, as the book came minus a dust wrapper, this temptation was easily resisted. However, this dark blue hardback book exudes authority with the literary hallmark of the Oxford University Press crest and book title stamped in gold on the spine and front cover. If further credibility is needed, the book's author was, until 1989, Professor of Archaeometry at the University of Oxford and he is, therefore, one of the foremost authorities in his field.

This book is about the minute quantity of light which can be obtained from mineral grains, mainly quartz and feldspar, when they are stimulated by a beam of light similar in strength to daylight, or by a beam of infrared radiation. The very small amount of the subsequently-emitted light can be used to determine the length of time which has elapsed since sediments containing the mineral grains were buried. This phenomena has allowed optical dating to become a firmly established method for geoscientists to date sedimentary processes of the past half a million years or so. Throughout the book the author refers to the work of others in the same field and in Chapter 5 he draws together the threads of some of their findings to cover a variety of sedimentary sites from across the world to show comparative chronstratigraphies of optical and calibrated radiocarbon dating.

By keeping the required level of physics and geoscientific knowledge to a minimum in the main body of the text, this book should appeal to the newcomer to this application of dating sediments. As an introduction to the subject, the first two chapters cover the concepts of luminescence, radioactivity and irradiation principles with later chapters giving a much more detailed account of the 'tools of the trade' together with the problems and practicalities of the evaluation of luminescence measurements in the laboratory. This is a text book with no plates but over one hundred good quality black and white line drawings which are often accompanied by rather lengthy explanatory notes. The more detailed facts have been consigned to 'Technical Notes' at the end of each chapter, the last of which ends on page 203; thus leaving 39 pages for the Appendices, 20 pages for the Reference List and a disappointing 5 pages for the Index.

Because this book is on a rather specialised subject the print run is small and it is, therefore, very expensive. This is a great pity because I found the book fascinating and relatively easy to read. I thoroughly enjoyed Chapter 5 - entitled 'Some Applications' which covered, among other things, aeolian deposits and earthquake-related studies. Being a bibliophile I could be tempted to buy the book but, in the cold light of day, I shall have to leave it for libraries to hold.

Tony Marter continuing Earth Science student

Global Energy Perspectives by N Nakicenovic, A Grubler & A MacDonald (eds), 1998, Cambridge University Press, 299pp, £16.95 (paperback) ISBN 0521642000.

This is a very thorough analysis of the present patterns of energy use worldwide where the editors have co-ordinated the work of about three dozen authors. It is a more sophisticated approach than the World Energy Council report *Energy for Tomorrow's World* (1993)

It is an attempt to look at future world energy consumption in 11 very separate regions; America (N & Latin); Africa (S & N with Middle East); Europe (W & Central); Russia; Asia (China, India & SE); and Australia. Each area is analysed under three broad scenarios of growth from high to low (ecologically-driven), with several sub-scenarios in between, looking forward to 2050 and 2100AD.

The book is well written, a fund of useful information, particularly in some of the diagrams which show the changing balance between the various forms of primary energy. Did you know, for example that in Western Europe we have moved from a position where coal has fallen from over 60% in 1960 to 20% in 1990, while oil/gas have risen from 25% to 60%. Nuclear and renewables make up the differences. Under all future scenarios this last category rises to more than 60% by 2100AD, while oil/gas is less than 20%?

Of course, like the much criticised *Limits to Growth*, produced by the Club of Rome in the early 1970s and used in the first OU Physical Resources Course, all projections about the distant future are likely to be proved wrong. But where we are going is a continuation of where we have come from. The lifetimes of large capital installations like power stations is measured in many decades, so that where our electricity comes from in 20 years time can be seen by looking at the present plant we have built. Even a problematic power station like that at Chernobyl is not easily replaced, much less substituted overnight by a safe renewable alternative energy source.

There are several useful general conclusions which emerge from these studies:

1) World energy demand is likely to increase by 2 to 5 times by 2100

2) Resource availability is unlikely to be a major problem, ie., there is not likely to be a shortage of geological resources - doom and gloom merchants please note!

3) Use of energy will become much more efficient, and regional differernces in supply and consumption will persist.

This is not a book to read at one sitting, but well worth dipping into when discussion turns to any sort of 'futurology', and a most of all useful reference to have on the shelf. In the nature of things it will probably be replaced in a few years time by a yet more thorough analysis which will reflect the new political situation, but then in geology as in life, everything is either eroded or covered up eventually!

Dr Dave Williams

Geology of the Country around Coventry and Nuneaton by D McC Bridge, J N Carney, R S Lawley & A W A Rushton, 1998 British Geological Survey, 185pp, £55.00 (paperback) ISBN 0118845209.

In North Warwickshire the largest structure visible for miles is the spoil tip of Judkins Quarry. This, and its associated landfill site, is the front cover photograph, set against the flat horizon of Leicestershire. This man-made hill, sitting as it does just on the watershed between the Severn and Trent river systems was at one time the subject of a proposal to use it as a dry ski slope. Black run, by its angle of repose!

The area under discussion in the memoir comprises geologically and economically important areas; from the Precambrian-Cambrian boundary sites around Nuneaton and Hartshill to the unconformably overlying Devonian/Carboniferous which hosts the only still working deep coal

mine in the North Warwickshire Coalfield. Apart from the Permo-Triassic beds the only occurrence of anything more modern is the glacial till covering much of the northern basin, the remnant of (mainly) the late Devensian and final ice retreat.

Starting in the middle, the sections on the coalfields and their working bring area plans of exploitation, in other words take the whole area and look at what was extracted and when, in one of the most valuable (and thick) coal seams of the area. As one whose grandfather worked as a miner in many of the pits mentioned this is almost family history. Sections show the diversity of the coal in other rocks types and a whole section is devoted to the events of the Devonian and Carboniferous and the tectonic movements involved in the formation of the structure of the area.

Moving back, the Precambrian and Cambrian sections are described collating all the information published over the past few years. In references names familiar within OU circles crop up: Richard Thorpe, Bill Gaskarth, Steve Cribb, Chris Hawkesworth, Mike le Bas to name the ones spotted. These and many others have contributed to the recent knowledge of the area, including a regional analysis of the structure of the Precambrian rocks which benefits from advances in remote sensing and geophysical techniques unavailable to earlier writers. Extensive analysis of the trilobite assemblage of the Hartshill and other formations is covered together with description and photographs.

Moving forward in time, the Quaternary glaciations have provided deposits of sands and gravels over much of the area, and this aspect is covered in more detail than was covered in other similar publications. To conclude there is the assessment of geological hazard from mining, landfill gas and methane from abandoned mine workings.

Photographs have already been mentioned and there is a section with significant illustrations from parts of the area including thin sections, rocks and structures. All in all, enough to give a very complete picture of the area. A very good book - wish I could afford it. Why are they so expensive?

Sandy Colby, BA Hons (Open) BSc (Open),
continuing MA Student of the University of Exeter

Dinosaur Impressions by P Taquet, 1998, Cambridge University Press, 244pp, £14.95, (hardback) ISBN 0521583721.
This is a translation from French. It is extremely readable and is affordable. Philippe Taquet is an eminent paleontologist and was director of the National Museum of Natural History in Paris.

The author had just finished his PhD in 1964 when offered a trip to Niger to look at some bones; unfortunately, they were expecting a learned professor. He found the bones superbly preserved just lying in the desert, after an interminable drive through the heat and silence you could hear. It's very descriptive and full of little anecdotes, like when the original boxes were eaten by termites, the new ones said 'drilling carrots' (drill bits) and the French customs wanting to know why they were importing carrots. In Morocco a surprised Berber sat knitting as a dinosaur was dug out of his wheat field. Another time Taquet was asked for a slide for a talk for executives to tell them to not be dinosaurs but he pointed out dinosaurs lived 155Ma and hoped they would too!

Quite a lot of the book describes the finds: amazing trackways in Gadoufaoua and the lack of tail impressions, large crocodiles, eggs from Outer Mongolia reached by travelling in lorries where you sat over the engine at 40°C (ouch!) and the 'sacred buffalos' remains from Laos. The dinosaurs etc. are all described well but a few more photos or drawings would be useful. The chapter about dates and relationship of groups of dinosaurs I found less interesting. There is a certain amount of historical information like Wegner and continental drift and the History of Genghis Khan and Marco Polo. The author is good at setting the scene.

The end of the book is naturally about the end of the dinosaurs but the author does not favour any catastrophic theories. He points out that most Jurassic dinosaurs are different from Cretaceous ones so extinctions were taking place all the time. Ammonites all died out well before the K/T boundary and in Montana all the bones are well below the boundary. He has alternate explanations, e.g. blue/green algae can concentrate iridium during times of marine regression.

The book is fairly light reading, full of anecdotes, a travel guide to exotic places and makes you green with envy as to why you'll never find the type of specimens Philippe Taquet found. Yes it is worth reading, even if you are not a dinosaur fan.

Wendy Hamilton BA Hons (Open) BSc

Tectonic Boundary Conditions for Climate Reconstructions, T J Crowley and K C Burke (eds), 1998, Oxford University Press, 285 pp, £55 (hardback) ISBN 0195112458.
This is a really exciting book - even for a novice like myself who has just scraped through S267, S269 and S339. Several familiar themes are revisited: Did Tibet cool the world? What made coal in Alaska and southern New Zealand possible in the Cretaceous? What really were the causes of the last glaciation? What was the effect of closing the Panama seaway and of opening the Drake Passage? Presumably this is a key publication for the team constructing S369 (the replacement for S338).

After a clear general introduction on the significance of tectonic boundary conditions for paleoclimate simulations, there are six chapters comprising twelve articles under the heads: Role of Continental Configuration, Role of Continental Elevation, Role of Epeiric Seas, Role of Ocean Gateways, Role of Bathymetry, and Tectonics and CO_2.

Most of the articles have a good clear summary or conclusions which make up for much of the text being (to me) rather impenetrable. For instance, in chapter 12, Sensitivity of Phanerozoic Atmospheric CO_2 to Paleogeographically Induced Changes in Land Temperature and Runoff, "changes in land runoff and land temperature .., due to changing continental size and position, have had only a minor effect on global weathering rate as it affects atmospheric CO_2. The effects on weathering of solar evolution, the rise and evolution of land plants, and changes in the relief of the continents due to mountain uplift dominate over continental size and position. However this conclusion may be revised in future work when the effects of ice sheets on both runoff and the mean temperature of land undergoing weathering ... are considered."

The disadvantages of the work are that many of the maps are illegible as they are printed in various shades of darker grey on dark grey, the references are in the text and not as footnotes (a dreadful habit to which scientists are addicted which makes much of their work unnecessarily unreadable) and the text is printed in double columns. How lucky OU students are with the very high standards of typography, maps and diagrams and all other aspects of book production!

George Monbiot wrote recently in The Guardian: "Scientists suffer perhaps more acutely than any others from the curse of the 21st century: complexity. Every discipline has been sub-divided by microtome. To prosper, they must narrow the scope of their enquiries to the extent that even people in related areas have no idea what they're talking about." Against that, one of the editors of TBC writes: "In this volume we present examples of how integrating solid earth and climate studies can lead to better understanding of both disciplines". It is a worthy aim, well carried out.

Philip Clark MA(Oxon) and continuing Earth Sciences student

Images of the Earth 2nd edition by S A Drury, 1998, Oxford University Press 203pp, £25 (paperback) ISBN 0198549970.
Unlike the 1st edition this is not a textbook on remote imaging, neither is it a casual read. This fully illustrated 'guide to remote sensing' makes fascinating reading, and is written in a style which will increase understanding of the subject for the non-professional reader, although the author's stated aim is also to reach people with power such as policy makers and politicians.

The global problems and disasters, both natural and man-made, which can and do have adverse effects on humanity, are discussed in the first

chapter using excellent photographic plates to illustrate examples cited in the text.

Starting with the anatomy and function of the human eye, the next two chapters are devoted to the technology of remote sensing and the instruments and systems at present in use to gather data, together with the methods used to interpret this data, both historically and up to the time of writing. The in-depth explanations are clear and made readily understandable with the relevant diagrams, figures and superb images, used to illustrate the various systems and concepts of remote imaging.

This is a fast growing science due to the increases in technology and therefore systems become obsolete, also, as the author makes abundantly clear, not all these technical advances are in the public domain.

In chapter four, the ways in which the information obtained by remote sensing can be used are fully discussed, ranging from national security, through earth sciences, meteorology and oceanography, to suggestions of ways in which the acquired information could be used to benefit mankind, especially in the deprived areas of the world.

The final chapter is devoted to the economics of remote sensing, and makes interesting reading. Once the initial costs of instrumentation and getting the system into orbit are met, the costs are not as high as might be expected.

Appendices 1 and 2 respectively provide information about training and sources for obtaining images. An extensive glossary provides definitions of terms used, and a list of further reading is given.

This is a very interesting and informative book, which the Author expects will soon need up-dating, look out for the third edition!

Muriel Wright BA Hons (Open)

The Geology of the Falkirk District by I B Cameron, A M Aitken, M A E Browne and D Stephenson, 1998, British Geological Survey, 106pp, £35.00 (paperback) ISBN 0118845411.

I was first introduced to the Geological Survey publications at about the age of 14. I still have my *British Regional Geology – Northern England* price 6 shillings (30p) and I consider them to be "Value for Money". The Geological Survey is tasked by Government to undertake the survey of Britain's geology in a similar manner that the Ordnance Survey is tasked to carry out the topographical survey.

This publication takes over where the *British Regional Geology – The Midland Valley of Scotland* finishes. Whereas the *Midland Valley of Scotland* is a general geology guide, the *Geology of the Falkirk District* is the detailed examination. My only criticism is that almost all the photographs are not in colour, but then sometimes colour photography does not always emphasise certain aspects that my be required. The BGS is starting to sell a less technical type of publication with its associated 1:50 000 map. That can only be for the better, as they will hopefully appeal to a broader range of people who are interested in the geology of an area, but don't want the "nitty-gritty" explanation.

Students of geology at all levels will find this book useful, especially when used with the 1:50 000 map. Together they show a student what to look for, where it can be seen and also gives the student a useful explanation. "Geology," as my tutor for A level said, "cannot be learnt from a book. It only gives a guide to what you will find in the field, what a particular structure will look like." This publication fulfils that requirement. Solutions are learnt best when one sees the real example. Whether a sedimentary "freak" or a "real rock nerd" this publication is for you.

The text is unusually divided not into geological succession, but into differing fields; for instance section six deals with volcanic successions and this alone covers the Lower Devonian and the Dinantian, Visean and Namurian. Section nine covers the geophysical data. There is a comprehensive list of references that will take the reader deeper into a particular subject. Coupled to this are two appendices: the first deals with borehole and mine shaft information, the other "Author Citations for fossil species." Added to that there is a good index. The whole publication runs to over 100 pages and includes 29 figures, 23 plates or photographs and 6 tables of information.

Gerard Vallely continuing Earth Science student

Evaporites: Their Evolution and Economics, by J Warren, 1999, Blackwell Science, 438 pp, £49.50 (paperback) ISBN 0632053011.

Floating freely on a body of water, the sun blazing overhead, a book in your hand and NOT sinking – How is this possible? And the significance of this experience for a review of a book about evaporites is only really apparent when you know the location for this idyll. I was reading *Zen* and the *Art of Motorcycle Maintenance* whilst floating on the Dead Sea, Israel. The Dead Sea is a hypersaline lake but, as this book reveals, evaporites are much more than evaporation exceeding precipitation and massive basin-wide drying-out events. The majority of evaporite development takes place out of sight beneath our feet.

On the whole the book is well structured starting, as the author states in his frontispiece, "at the beginning". What is an evaporite? The text is peppered with a multitude of modern day and geologic examples. The examples, unlike in some other books, are not exclusively from one continent which makes the book accessible to a much wider audience than books whose examples are solely from a single continent. The text is well illustrated with clear diagrams that enhance the text. However, given the breadth of examples, there is a total lack of photographs. As an example; the author states that "In the Messinian … excellent onshore exposures and core ..." why not show us this excellence so all can marvel at them? It would enhance the text immeasurably. I have seen some of these Messinian deposits and 2m long Christmas Tree selenite crystals juxtaposed with gypsum clastic deposits are a delight (sorry no photograph) – see (or not in this case) how a photograph would aid your appreciation of what I saw.

The author takes the reader from "What is an Evaporite?" through their formation to evaporite-metal associations via tectonics. There is a mass of data written in the usual dense academic style. This makes for an in-depth read which takes time. Your time is well rewarded, but you may need a geological dictionary as a companion on this particular journey. Students of S338, S339 (the tectonics) and S268 (the economic geology) will find this tome useful and will stretch their knowledge. Though given its price I would suggest borrow, rather than buy it, initially.

Two points of criticism: an abstract or chapter synopsis would be useful as a guide to the general content of each chapter to allow readers to choose which chapters are of particular interest to themselves, given that the author is aiming the book at a very wide audience. A set of suggested further reading or references worth reading would be useful, especially as the author wishes this book to be "an evolving work that broadens the way explorationist and researchers will look at evaporites".

The book is well worth a dip into, much like the Dead Sea was when I was reading my book. The author makes it an invigorating and interesting subject by his style of writing and the subject matter will stretch your areas of knowledge across a wide range of geological areas. An excellent comprehensive base for understanding evaporites, their formation and evolution and therefore a book that is worth the effort to read.

Ivan Finney continuing Earth Science student

Dynamic Earth: Plates, Plumes and Mantle Convection by G Davies, 1999, Cambridge University Press, 458 pages, £24.95 (paperback), ISBN 0521599334.

This book encapsulates current thinking about the mantle processes which underlie plate tectonics and hence most geological processes. It is an advanced text, aimed at graduate students and researchers, but also appealing to geologists with a broad interest base.

In the book, the author presents the current most useful model of mantle dynamics. Setting out the physics from first principles, it is eminently readable. Although there is some maths that is rather taxing for the uninitiated, the author "flags" the more complex sections as "advanced", so that the more wary can avoid falling at these mathematical hurdles.

The book is divided into four parts, starting from an introduction and history of ideas that underlie our understanding of the processes of convection in the Earth's solid mantle and it connects the model to its place in geology. Each chapter is comprehensively referenced.

The second section acts as an information base, so the ensuing 'mantle convection' discussion proceeds unhindered. The two basic physical processes, which need understanding, are fluid flow and heat conduction. These are discussed in accessible terms, with excellent, down-to-earth analogies!

In "Essences", we come to the core of the subject, which gives the general picture as the author can best assess it. Convection is discussed as a general phenomenon, which in this case has two main modes of expression, plates and plumes. There is a fascinating discussion of laboratory modelling and how this relates to plume development and the eruption of flood basalts. Each chapter has a good introduction and reiterates, concisely, the ideas in previous chapters. Among the most interesting points are how plate and plume modes appear complementary, and the rôle of plumes in triggering tectonic change. The ideas synthesized in the final chapter of this part, give a sense of all the aspects of the mantle convection concept as it stands.

In the final part of the book, the author addresses two complementary aspects, which add focus to the dynamic processes operating in the mantle, the geochemical and thermal evolutionary aspects. He stresses the point that attention to both chemical and physical processes is needed for a fully comprehensive interpretation.

This is an excellent text, treating us to a very accessible exposition of a complex, but essential aspect of our subject.

Diana M Smith BSc (Hons), BA (Open), OU Tutor

Geology of the Carrick - Loch Doon District by J D Floyd, 1999, British Geological Survey, 122pp, £37.50 (paperback) ISBN 0118845403.

This BGS memoir is all part of a government sponsored programme to describe the geology covered by the BGS 1:50 000 maps throughout the country, as well as the BGS Regional Guides. The book itself is made up of twelve chapters of varying lengths describing the geology covered by BGS 1:50 000 map 8W and 8E for the Carrick - Loch Doon district. The geology covered includes a large area of the Southern Uplands Terrane, the Southern Upland Fault, and a small section of the Midland Valley Terrane in the north. The rocks in this area are mostly Ordovician - Silurian turbidite sequences in the Southern Uplands Terrane, plus the Devonian granite intrusions. It also covers the upper littoral Lower Palaeozoic sequences in the Midland Valley Terrane, with brief references to the Ballantrae Complex, Lower Devonian conglomerates and volcanics and an outcrop of Carboniferous strata.

After a brief introduction the regional stratigraphical framework is discussed. Chapters 3-7 discuss the sedimentary rocks and volcanic sequences in all periods exposed in both the Midland Valley and Southern Uplands Terranes. Chapter 8 discusses the structure in both terranes, covering folding and faulting, main deformation events, shear zone, and post-D1 structures.

Chapters 10, 11 and 12 are all short chapters on geophysical interpretations, economic geology, and Quaternary deposits found in this district.

The in-depth discussion/description of the rocks found in this district is very good, backed up by a comprehensive bibliography and appendices. At £37.50 it is rather expensive unless really interested in this district, therefore, the best place for it is in specialised libraries, or reference sections in public libraries. Despite the excellent coverage this book gives to the geology in the district, do we really need this book as well as a Regional Guide, plus geological maps? Obviously BGS feels that there is a niche for these publications.

Andrew Fleming continuing
Earth Sciences student

The New Solar System (4th Edition) by J K Beatty, C Collins Petersen & A Chaikin (eds), 1999, Cambridge University Press, 421pp, £24.95 (paperback) ISBN 0521458307.

This book is a collection of chapters by a series of authors but all presented in a similar style. Each appears to present a reasonably easy-to-understand introductory section before being followed by a more in-depth explanation.

The subjects covered in the twenty eight chapters are: "Exploring the Solar System" by David Morrison; "Origin of the Solar System" by John A Wood; "The Sun" by Kenneth R Lang; "Planetary Magnetospheres and the Interplanetary Medium" by James A Van Allen & Frances Bagenal; "Cometary Reservoirs" by Paul R Weissman; "The Role of Collisions" by Eugene M Shoemaker & Carolyn S Shoemaker: "Mercury" by Faith Vilas; "Venus" by R Stephen Saunders; "Planet Earth" by Don L Anderson; "The Moon" by Paul D Spudis; "Mars" by Michael H Carr; "Surfaces and Interiors of the Terrestrial Planets" by James W Head III; "Atmospheres of the Terrestrial Planets" by Bruce M Jakosky; "Interiors of the Giant Planets" by William B Hubbard; "Atmospheres of the Giant Planets" by Andrew P Ingersol; "Planetary Rings" by Joseph A Burns; "Io" by Torrence V Johnson; "Europa" by Ronald Greenly; "Ganymede and Callisto" by Robert T Pappalardo; "Titan" by Tobias Owen; "Triton Pluto and Charon" by Dale P Cruikshank; "Midsize Icy Planets" by William N McKinnon; "Small Worlds: Patterns and Relationships" by William K Hartmann; "Comets" by John C Brant; "Asteroids" by Clark R Chapman; "Meteorites" by Harry Y McSweeny Jr; "Life in the Solar System" by Gerald A Soffen; "Other Planetary Systems" by R Paul Butler

As it can be seen from the list of chapters the book covers a wide range of topics, some written by well known 'names', each is illustrated with colour and black and white photographs, diagrams and drawings. Many of the photographs and radar survey mapping reconstruction's are from NASA interplanetary spacecraft missions and show the surface features in great clarity. The planetary formation processes, which are probably more relevant to geologists, are covered in many of the chapters. Meteorites are well represented and their effect on not only the past but their probable effect on earth in the future is explored. At the end of the book there are tables listing 3 pages of 'Potentially Hazardous Asteroids' and a further 3 pages of craters from asteroids which did not miss! (a sobering thought)

This is an informative, well illustrated book and not extravagantly priced.

Alan Hamilton BA Hons (Open)

Geology of the Irvine District by Dr S K Monro, 1999, Memoir for 1:50 000 Geological Sheet 22W and part of Sheet 21E (Scotland). British Geological Survey, 140pp, £40 (paperback) ISBN 0118845500.

Covering the area from Largs and Lochwinnoch in the north to Troon in the south and flanked by the Firth of Clyde and part of Great Cumbrae to the west, this long awaited publication is now available. This resurvey of the district was carried out between 1968 and 1982 by I B Cameron, A Davies, S K Monro and D Stephenson.

The memoir comprises fifteen sections and follows the familiar format of BGS memoirs. Beginning with an historical account of the district's economic resources in which coal, limestone and ironstone provided the foundation for industrial development, with sand and gravel being quarried to a lesser extent, extraction goes back a long way into history. Presently crushed rock aggregate, limestone, and Carboniferous mudstone for brick making are worked.

The Lower Devonian rocks of the Hunterston peninsula are described followed by the coastal strip of Upper Devonian between Largs an Ardrossan. The Lower and Upper Carboniferous geology of the area from Tournaisian to Westphalian is covered in some detail. Described are the Kinnesswood, Ballagan and Clyde Sandstone Formations of early

times, succeeded by the Clyde Plateau Basaltic Volcanics with a thorough account of their petrology being given. These belonged to the Strathclyde Group and form much of the high ground in the north today. The Visean/Namurian limestone has been divided into three formations: Lower Limestone, Limestone Coal, and Upper Limestone. The Passage Formation of coarse grained sandstones with seatearths and clays prograde into the Westphalian Lower, Middle, and Upper Coal Measures which have been extensively mined. The local names applied to some of these beds makes interesting reading.

A biostratigraphical record for the principal named Carboniferous fossil horizons is reviewed in ascending sequence and some re-identification of earlier fossil collections has been included. The Permian sandstones and volcanics of the Mauchline Basin, the only representatives of this period in the region, are looked at briefly and a recent analysis of the lavas is given. The intrusive igneous rocks in the Irvine district comprise sills, dykes, vents and plugs and range in age from early Devonian to the Palaeogene Period; again recent analysis is provided, along with a table of xenolith types found in vents by Hunter and Upton in the 1980s. Geophysical evidence from work done from the 1960's onwards has provided much new information on the underlying structure. Gravity, aeromagnetic, and seismic survey data have all been used to interpret the history of this area of the Midland Valley of Scotland

The author, a 'weel kent face' in OUGS circles, has provided us with a good all round picture of the Irvine district, and will be of great interest to those who live in, or have an interest in the region. It is an ideal information source and the comprehensive reference section gives the reader an opportunity to follow up particular aspects of interest.

Stuart Fairley BSc (Open)

Holiday Geology Guide: Scarborough and Whitby - The Jurassic Coast by B Cox & J Powell, 1999 British Geological Survey, A3 folded, £1.95, ISBN 0852723199.

As someone who is only vaguely familiar with this coastline, I found that this neat guide is full of information about the geology of the area, it is very easy to read, and is clearly illustrated . There are good photographs showing the main geological successions of the Jurassic as well as the local formations. This is clearly laid out in a geological column giving all the divisions.

The reader is given not only a geological guide, where a brief depositional setting is offered, but a fossil guide (and where they can be found) and some relevant mineralogical and industrial archaeological background pertaining to the area.

The guide also offers a brief overview of the people who have made significant contributions to our knowledge of the Yorkshire coast geology and where a visitor can find relevant collections and displays. I felt that the panoramic map is perhaps a bit simplified, but using corresponding colours in the geological column makes it easy to see and appreciate the succession.

This guide would certainly be useful as a basic introduction to the geology of the area, especially to beginners, and is likely to spur the reader on to more extensive studies both in reading and in the field. I'm now considering a holiday there! At £1.95, well worth it.

Wendy Owens continuing Earth Science student

James Hutton – Present and Future by G Y Craig & J H Hull (eds), 1999, Geological Society, London, 184pp, £59.00, (hardback) ISBN 1862390266.

This slim volume contains nine of the papers persented at the Geological Society Conference in Edinburgh in 1997 to commemorate the bicentenary of the death of James Hutton, the founder of modern geology. Many of the world's most eminent Earth Scientists and Science Historians were present and the challenging lectures exploring Hutton's famous dictum "no vestige of a beginning, no prospect of an end," covered a wide spectrum of Earth Science past, present and future.

For the historian, examples include Donald McIntyre's admirable précis of Hutton's life and the achievements of the Scottish Enlightenment, and P J Wyllie's exposition of experimental igneous petrology involving the theories of Hutton, a plutonist, verses Hall, a neptunist. For the geochemist, there is Werner Schreyer's fine synthesis of metamorphic processes, with special reference to the Alpine orogeny – a lecture which provoked much debate over the various forces involved. In fact, part of the appeal of these lectures is that they deliberately include theories which are controversial and which were meant to capture the attention of a very demanding audience. A prime example is Don Anderson's "Theory of the Earth," which explores the paradoxes and logical inconsistencies behind accepted views on the origin of plumes and hot spots, it being postulated that mantle dynamics are controlled from the top rather than the bottom of the system. Gaia, Daisyworld and even uniformitarianism are subjected to similar critical scrutiny in other lectures, and it is a great pity that Maureen Raymon's doom-laden CO_2 scenario is not included.

This little book is a "must" for those, like myself, who were lucky enough to have attended the Conference. It is certainly not a textbook, but is a challenging and stimulating read for those with some knowledge of the subjects covered. However, I fear the price will put it beyond the reach of most prospective purchasers.

Jill Kemp BSc (Open)

Evolutionary Catastrophes - The Science of Mass Extinctions by V Courtillot, 1995 (translated by J McClinton 1999), Cambridge University Press, 173pp, £14.95 (hardback) ISBN 0521583926.

In this slim volume Courtillot examines the hypothetical causes of mass extinctions. He pulls together the different scientific threads to determine whether the journalistically popular "impact theory" is correct or whether there may be a different reason. He uses all branches of Earth Science to support his arguments and bases his book on work by many Earth Scientists.

The author begins by looking at mass extinctions and the history of life and follows quickly with a discussion of the impact theory from its origins and through its development and supporting science. He goes on to examine massive volcanic activity and its causes. Having explained both theories, he is then able to provide a clear explanation to which is the most likely and, in one diagram (at least for me), provides the clearest picture of extinctions, their cause and the relationship to the main geological intervals. Were repeated extinctions caused by a one second impact or did they take place over millennia?

The book is very readable and provides a clear and concise picture for anyone interested in the subject. The text is well written and supported by clear footnotes where necessary and a comprehensive glossary. It is let down a little by one or two of the figures that are rather dark. Instead of a bibliography, he has provided an index of authors for those who wish to take it further.

I chose to review this book as I had just completed S269, was about to begin S365 and wanted a bit more background. I was not disappointed and recommend this book for those at any stage in their studies or knowledge. It is written for a general audience but should not be missed by professionals.

Yes, I know I have not told you what his conclusion is - you deserve to read it yourselves.

Mike Hermolle Continuing Earth Science student

Antarctic Marine Geology by John B Anderson, 1999, Cambridge University Press, 289 pp, £70.00 (hardback) ISBN 0521593174.

This is a fascinating and well-produced volume which would be of interest to anyone reading the Oceanography or Sedimentary Processes courses. Its chapters cover, in considerable detail, the environment, geological and glacial history, sedimentology, geomorphology and evolution of the continental margins of Antarctica. The text is amply supplied with maps, photographs and diagrams of high quality.

It is the work of a single author who has considerable experience in Antarctic exploration. He draws together the many fields of research into the geological processes that have formed this unique continent. The book is well referenced throughout and has over thirty pages of bibliography. It acknowledges the gaps in knowledge of the continent and its surrounding ocean, and suggests further possible fields of study. There are excellent short summaries throughout the text.

The global influence of Antarctica is massive. Oceanography students will be well aware of its significance in oceanic current production and weather patterns. This, the coldest, driest, and windiest continent on earth, has the potential to raise sea-level by two hundred feet. The instability of the West Antarctic Ice Sheet is a real cliffhanger. The delicacy of the feedback between ice-shelves and water masses in relation to global warming is a crucial factor. Ice core studies may yet provide the answer to the question of whether global warming is part of a natural climatic cycle or man-made.

There is a thorough description of the evolution of East Antarctica by passive continental separation from Africa, India, Australia and New Zealand with the break up of Gondwanaland. This includes sequence stratigraphy and seismic interpretation of the continental margins. The very different evolution of the Pacific-Antarctic margin of West Antarctica with its complex subduction history and terrane accretion is explored in detail.

Perhaps the only reassuring thing about Antarctica is its circumpolar thermal isolation. Since the Tasman Rise subsided and the Drake Passage opened up this maintains its cryosphere. But this very isolation and change from temperate to polar climatic conditions has resulted in decrease in the precipitation without which the ice-sheet cannot be maintained. The enigma of Antarctica remains.

The author indicates where further research is needed. Where there is controversy or lack of information he fully explains contrary arguments. There is nothing abstruse in this book. It is easily readable and refreshingly lacking in obscure language. It deserves a place in any geological library. I am looking for a second-hand copy,

A J Sheehan BSc Hons (Open)

Introduction to Seismology by P M. Shearer, 1999, Cambridge University Press, 260pp, £18.95 (paperback), ISBN 0521669537 and £50.00 (hardback), ISBN 0521660238.

Upon receipt of this book with its innovative and attractively-coloured cover, my expectations were immediately raised but, once opened, the volume had the look and feel of a text book for which the author, a professor of geophysics at the Scripps Institution of Oceanography, University of California, makes no apology.

The book, which is a distillation of a series of lecture notes given by Professor Shearer to graduate students in geophysics, would probably be seriously off-putting to the average earth science student with pages of equations more usually associated with, and in many cases somewhat beyond, the 'A' Level Pure Math syllabus. The book starts off gently enough with an excellent chapter on the 'History of Seismology' before catapulting the reader into the theory of 'Stress and Strain' where the world of cubic equations, differential calculus and matrices is encountered.

This level of presentation sets the tone for most of the book's remaining chapters which cover: seismic wave equations, ray theory: travel times, inversion of travel time data, ray theory: amplitude and phase, reflection seismology, surface waves, source theory, earthquake prediction and finally a miscellanea chapter. At the end of each chapter there are exercises that often require a knowledge of the scientific computer language FORTRAN, as well as differential and integral calculus. Finally, there are four appendices namely: a math review of vector calculus and complex numbers, the eikonal equation, FORTRAN 77 sub-routines, and time series and Fourier transforms.

Despite the plethora of mind-numbing mathematics which inevitably has to accompany this type of text book, there are many little 'gems' of non-mathematics to be enjoyed along the way such as the section on ray nomenclature and the search for the PKJKP seismic P-wave, the Holy Grail of seismologists, and the use of focal spheres to display earthquake focal mechanisms, as 'beach ball' images, onto maps.

In summary then, an excellent text book that meets its aim of providing 'an approachable and concise introduction to seismology' for the 'upper-division undergraduates or first-year graduates in geophysics'. For those of us who have not yet achieved that level of knowledge, this book is rather too 'classroom' orientated and, despite the many clear figures and well laid out text, does little to stimulate the more general reader and is a case, like many 'Introductions', of being pitched at a higher level than the title would suggest to the unwary.

Tony Marter, continuing Earth Science student

Late Cenozoic Environments and Hominid Evolution: a tribute to Bill Bishop by P Andrews and P Banham (eds), 1999, Geological Society, 276pp, £69 (hardback) ISBN 1862390363

This is not a popular science book for the casual reader as it consists of a series of scientific papers by students and colleagues of the late Bill Bishop. Professor Bishop worked in East Africa before becoming Lecturer in Geology at the University of London, later being appointed to the Chair of Geology at Queen Mary College.

The book is in three parts, the first two on East Africa, the third being mainly concerned with the British Quaternary. The first section contains papers on the Miocene fossils of Uganda and includes discussion of recent discoveries of the oldest known hominoid, *Morotopithecus bishopi*. Part two examines the environmental and archaeological evidence from the Tugen Hills area of the Kenyan Rift. Strata in this region fill a gap not datable from the sedimentary sequence in other parts of Africa. Papers on samples from dentine to tuff offer interpretations of paleoenvironments and paleoecology from late Miocene to Pleistocene.

Quaternary environments are the subject of the final section, initially at sites in Britain, with paleoclimatic indicators as diverse as pollen, peat and herpetofaunal remains. The pollen diagrams will be familiar to those who have studied S269, Earth and Life. The final paper returns to Africa, with a study of paleoenvironments of the Kalahari in Southern Africa.

I enjoyed this book immensely, the subject of hominid evolution fascinated me long, before I became a 'proper' earth science student. An anatomical reference work is useful when reading part 1, with its detailed discussion of mammal bones. I have only one criticism, the many clear in text illustrations all have detailed captions but the photographs of Bill Bishop have none.

Pat Dowling BSc Hons (Open)

Cornish Pebbles by A Goode, 1999, Holiday Geology Guide, British Geological Survey, A3 folded, £1.95, ISBN 0852723164.

"What's this, Mum?" "It's a pebble, darling." " Yes, but what is it?"

Parents familiar with this type of question may now be grateful for an inexpensive and colourful guide including, in the A3 centre spread, a posed and keyed photograph of the multitude of common (and not so common) variety of pebbles to be found on Cornish beaches. This is an excellent way for those who don't know to compare what they've found with a known identified photograph and try to identify it (and indeed reading it has enables identification of a rock collected high up on Dartmoor at least ten years ago)

In the guide are sections on the formation of pebbles, the geology of Cornwall, and, perhaps more importantly, the composition of the illustrated pebbles so that the type of question referred to above can be answered. I have been critical of other publications in this series about West Cornwall both from their content and by virtue of skimming over the subject and missing out significant parts, but this has attacked a different market in a much more limited area and as such is much more useful.

John Colby BA Hons (Open)